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SUSTAINABILITY ASSESSMENT OF A MUNICIPAL UTILITY COMPLEX: A SYSTEM OF SYSTEMS APPROACH

by

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ABSTRACT

Construction of municipal utility complexes has to support continuing population growth, economic development, and a widespread of social interest in environmental preservation. Municipalities face challenges in designing, constructing, and operating environmentally sustainable utility complexes, and their primary goal in developing such a complex is to minimize the environmental impact resulting from energy production and waste treatment (both liquid and solid), management, and disposal. However, decision and policy makers lack a system of systems approach that takes into account multiple interdependent systems comprised of the functional system (infrastructure, facilities, operations within the complex…), the economic system, the social/cultural system, and the environmental system (environmental impact on air, water, soil…). This research proposes a decision support system (DSS) with a new methodology using Vensim software and system dynamics methodology to assess the sustainability of a municipal utility complex system. This DSS incorporates 1) multiple interdependent systems, 2) multiple sustainability/performance indices, and 3) composite sustainability index. Engineers, managers, and researchers should benefit from a system of systems perspective, and from the application of a sustainability assessment method that is developed to provide an environmentally-conscious design, construction and management. Although a municipal utility complex is built with synergistic opportunities for integration of processes of a wastewater treatment plant, a resource recovery facility (aka waste-to-energy (WTE) or incineration facility), a material recycling facility (MRF), and a landfill; engineers tend to use the traditional sustainability assessment methods only to assess the life cycle (LCA) of each system's process over time. They might not necessarily incorporate an assessment based on system dynamics of the functional, economic, environmental, and social/cultural systems. Data from a case study is utilized in this dissertation based on the municipal utility complex in Pasco County in the western region of the State of Florida, USA.

To my parents, who wanted most of all a good education for their children

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The following people have taught me the meaning of support

Dr. Amr Oloufa

Dr. Omer Tatari

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LIST OF ACRONYMS

AWWA	American Water Works Association
BEACH	Beaches Environmental Assessment and Coastal Health
CBA	Cost-Benefit Analysis
CDC	Centers for Disease Control and Prevention
CWA	Clean Water Act
CWSRF	Clean Water State Revolving Fund
DSS	Decision Support System
EFAB	Environmental Financial Advisory Board
EFC	Environmental Finance Center (Network)
EPA	U.S. Environmental Protection Agency
EPHI	Environmental Public Health Indicator
FCI	Facility Condition Index
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FMSS	Facility Management Software System
GIS	Geographical Information System
MUC	Municipal Utility Complex
W2E	Waste-to-Energy

CHAPTER 1
INTRODUCTION

1.1 Background

The 21st century commenced with an approximate population of six billion, a more global economic progress in the 20th century than all the prior centuries combined, and a substantial burden on the world's natural environment (Horvath, 1999). Municipalities are providing the infrastructure to support this continuing population growth, economic development, and a widespread of social interest in environmental preservation for the ever improving lifestyle of the world's population. They face challenges in designing, constructing, and operating environmentally sustainable systems, and their primary goal in developing such systems is to meet the needs of, and aspiration of, the present generation without compromising the ability of future generations to meet their needs (WCED, 1987). Therefore, they aim at minimizing the environmental impact resulting from energy production and waste treatment (both liquid and solid), management, and disposal. While there is much discussion about the ways to provide the needed municipal systems and the additional infrastructure without lowering environmental quality and quality of life, accurate sustainability assessment of such systems is still an elusive goal, especially the sustainability assessment of a municipal utility complex (MUC).

A municipal utility complex is a successful strategy of industrial symbiosis that uses inter-system collaboration to promote sustainable development and implement industrial ecology. The complex is also referred to as an eco-industrial park, and consists of interdependent subsystems of a wastewater treatment plant, a resource recovery facility (aka waste-to-energy (WTE) or incineration facility), a material recycling facility (MRF), and a landfill. Waste is no more treated as the valueless garbage, rather is considered as a resource. Resource recovery is one of the prime objectives in a municipal utility complex. Waste management options include resource recycle, recovery and energy generation facilities from the solid waste. Waste-to-energy (WTE) conversion is considered as one of the optimal methods to solve the waste management problem in a sustainable way.

The idea of an eco-industrial park has been first described during a presentation at the United Nations Conference on Environment and Development (UNCED), Rio de Janeiro 1992, and has become well-known from 1993 on in the USA through the introduction of Indigo Development to the US-EPA (Lowe et al.1998).

The MUC being one of the largest and most important municipal system, and at the same time one of its largest impact source on the environment, necessitates a proactive approach in assessing its sustainability. An approach that incorporates all interdependent systems within the MUC, or as more commonly known as a system of systems approach.

In this approach, municipal utility complex "differs both from current economic practice, where only phenomena that can be quantified and are captured in the price structure are deemed to matter for most resource allocation and consumption decisions, and from current environmental regulation practice, which emphasizes non-systemic, single dimensional definitions of, and responses to, environmental perturbations" (Allenby 1992).

Although a municipal utility complex is built with synergistic opportunities for integration of processes of a wastewater treatment plant, a resource recovery facility (aka waste-to-energy (WTE) or incineration facility), a material recovery facility (MRF), and a landfill; engineers tend to use traditional sustainability assessment methods to assess the life cycle (LCA) of each system's process over time. They might not necessarily incorporate an assessment based on the system dynamics analysis of the sub-systems.

How systems within the complex should interact, as well as the resulting strategies cover a wide range of features. While some researchers merely refer to connecting material and energy flows between the sub-systems (S. Manahan 1999 / Schön & Kunze 1999), others go far beyond that, addressing integration into the surroundings, construction technologies and the management (Lowe et al. 1998). Others additionally include the social factor, pointing out the fact that "Valuing natural resources means also valuing human resources" (Cohen-Rosenthal et al 1998), thus arguing in line with the three components of sustainability outlined in the Agenda 21 (UNCED 1992) - the economic, ecological and social components (Côté & Cohen-Rosenthal 1998).

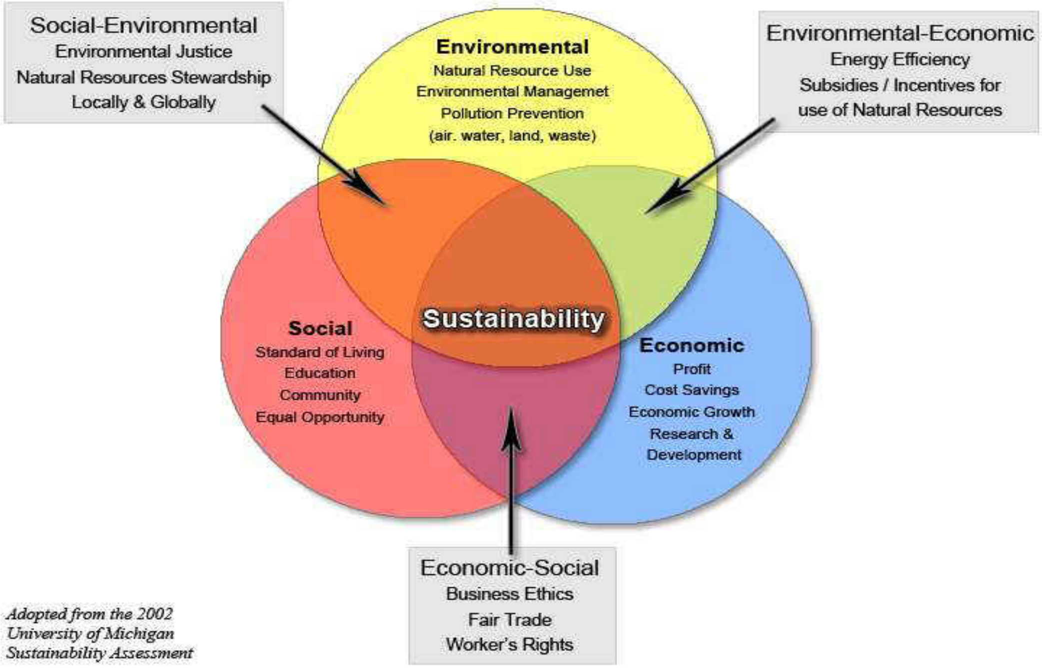


Figure 1-1. The Three Spheres of Sustainability (Rodriguez et al., 2002)

1.2 Problem Statement

The decision makers who make policy, plan, and invest in a municipal utility complex are basing their decision only on the environmental impact of the complex when assessing its sustainability. They are not using a scientifically or logically reasonable methodology based on a broad understanding of the whole structure of the utility complex system and its interdependencies and relationships with other systems. In addition, they lack a decision support system that is practical and can be utilized easily and flexibly in the decision making processes. This practicality can be facilitated by adopting decision support system architecture for the use of utility complex decision makers.

1.3 Objectives of the Research

The objective of this research is to develop a decision support system and methodology for decision makers to help them assess the sustainable development of a municipal utility complex from a system of systems approach. The accomplishment of this objective involves extensive and detailed analyses of the municipal utility complex system and related socioeconomic and environmental systems.

A detailed research matrix table is provided in Table 1.1, and the following paragraphs provide a summary of the analytical methods that are performed in this research.

1. Identify the various subsystems constituting a municipal utility complex system. This task is then further extended to include investigations of interrelationships

among the complex and socioeconomic and environmental systems that affect the physical and functional condition of the complex.

2. Develop a municipal utility complex model as a base for the decision support system. The model is composed of demography, solid waste management, liquid waste management, resource recovery, and recycling, functional, regional economy, finance, and appraisal subsystems.
3. Validate the developed model to improve the reliability and credibility of the model. This task necessarily involves a process of parameter estimation based on observed socioeconomic data.
4. Predict basic waste, socioeconomic, and demographic variables. As they are interconnected and thus their values change with other variables, identification of their interrelationships is a key task.

Table 1-1 Research Matrix

Research Question	**Background**	**Method**	**Databases**	**Analysis**	**Outcomes**
1.0 What is the proposed system of systems methodology to assess the sustainability of a municipal utility complex (MUC)?	Environmental, Economic and Social Assessments	Literature Review	Journal articles	Conceptual Analysis	Definitions Sustainability Indicators
2.1 What is the relative environmental impact of a sustainable municipal utility complex (MUC)?	Potential contribution of the MUC'S to the environment with a minimum environmental stress	Hybrid Analsis	Field data	Process based and Economic input-output based life cycle assessment	Energy, Greenhouse Gases, Acidification compounds
2.2 What is the relative economic impact of a sustainable municipal utility complex (MUC)?	Potential contribution of the MUC'S to the economy with a minimum economic stress	Economic Analysis	Economic data	Indices Analysis	Economic indicators and indices
2.3 What is the relative social impact of a sustainable municipal utility complex (MUC)?	Potential contribution of the MUC'S to the society with a minimum social stress	Social Analysis	Demographics	Indices Analysis	Social indicators and indices
2.4 How to model the interrelationships or causalities among indicators of a municipal utility complex (MUC)?	Measure of MUC sub-systems interrelationships	System Dynamics	Prior data	System Dynamics	Composite index
3.0 How to model and simulate the sustainability of a Municipal Utility Complex from a system of systems approach?	Ability to assess the system by running different scenarios of input and output variables	MUCM Model	Pasco County ISWM – West Pasco Complex	Modeling & Simulation	Vensim Scenarios
4.0 What are future recommendations and implications for policy and decision making?	Explore alternatives to inform design and policy analysis	Site Design	_	Exploratory Analysis	Design alternative

1.4 Scope and Limitations

The scope of this research may be expressed in terms of functional, external and time contexts. In the functional context, four functional dimensions of a municipal utility complex are considered. They are the waste-to-energy facility, material recycling facility, landfill, and wastewater treatment plant. In the external context, social and economic factors impacting the complex are considered. In the time context, the data available for building the model is based on a certain time frame, and the prediction of future utility conditions and management activities is performed for a 20-year period.

This research focuses on the development of a model base by presenting the municipal utility complex model. The model base constitutes the backbone of the construction of a DSS, and model building governs and leads the construction procedures of the other components of a DSS. The establishment of a complete version of a decision support system requires extensive research tasks, each of which should be specialized for the construction of a model base, a data base, and a display base. Building a DSS for a municipal utility complex must be a collaborative work among experts from various fields: utilities planning, engineering, operations and management, computer science, and administration. Therefore, this research does not analyze all policies affecting the management activities of utility complex, neither does it evaluate these policies in terms of their benefits and costs. The benefits are calculated from savings in utility user costs, and the costs are obtained from annual maintenance costs and capital investment costs. This research is also limited by the time frame for data availability and the subsequent performance indicators.

1.5 Value of the Research

Decision and policy makers will be able to use a decision support system (DSS) based on a system-of-systems approach that takes into account multiple interdependent systems comprised of the utility system (all infrastructure, facilities, operations…), the socio-economic activity system (social, cultural, economic/financial…), and the environmental system (environmental impact on air, water, soil…). This research proposes a DSS with a new methodology for assessing the sustainability of a municipal utility complex system. The DSS incorporates 1) multiple interdependent systems, 2) multiple performance indices, and 3) composite sustainability index. In addition, engineers, managers, and researchers should benefit from a system of systems perspective, and from the application of a hybrid sustainability assessment method that is developed to provide an environmentally-conscious design, construction and management.

1.6 Organization of the Research

This dissertation is proposed to consist of the following chapters described as:

a. Chapter 1 presents the problems faced by decision makers regarding municipal utility complexes, their sustainability assessments, and the background, necessity, objectives, and scope of this research.

b. Chapter 2 reviews literature regarding municipal utility complexes and the concept of decision support systems. Research regarding civil infrastructure, waste-to-energy facilities, wastewater treatment plants, landfills, materials recycling facilities and management are reviewed in detail. The application of the DSS to infrastructure planning and management is also outlined.

c. Chapter 3 reviews the concept of sustainable development and the current movements toward sustainable development. Various perspectives for viewing sustainability are examined, and the importance of adopting systems modeling to achieve sustainability in planning and management is discussed. A simple mathematical model is provided to help understand the implementation of the concept of sustainable development as presented in this research.
d. Chapter 4 outlines the research requirements and the corresponding methodology to be adopted in this research. A comprehensive view of the systems approach presented in this research and system dynamics is provided.
e. Chapter 5 is devoted to the explanation of the structure of the municipal utility complex model. A detailed description of the model is provided for each of the following subsystems: solid waste management, liquid waste management, demography, functional, regional economy, finance, and appraisal subsystem. Identification of causal links among these subsystems and development of the whole framework of the model are focused upon in this chapter. The explanation of the model is facilitated by providing causal diagrams for each subsystem. As the overall performance and credibility of the research depend on model building, this chapter should be regarded as the core of this dissertation.

f. In Chapters 6 and 7, the model is verified and validated by observed conditions so as to measure the reliability of the model. The model parameters are estimated based on observed municipal utility and socioeconomic data. The model's performance is examined by comparing estimates generated through the model to observed values of key variables. The model verification process described in this chapter and the model development process explained in the prior Chapter are iterative. In other words, the model is repeatedly redefined, updated, or rebuilt until the outcomes of the model fall within an acceptable range of deviations from the real data.
g. Simulation and policy analysis are implemented in Chapter 8 by running the constructed and validated model. Estimates of key input variables for a certain period are presented, and the corresponding output originates from reasonable predictions of these key variables.
h. Finally, in Chapter 8 as well, for each scenario modeled, a summary of the research findings are discussed. Based on the outputs, recommendations concerning the municipal utility complex and the construction of a decision support system are made in the context of sustainability. The limitations of this research and implications for future researches are also discussed.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A growing body of literature discusses the evolution, structure, inner workings, and performance of eco-industrial parks or industrial symbiosis in general. The Denmark Kalundborg industrial symbiosis example is commonly cited to illustrate the success of such a project. This eco-industrial park (which is comprised of industrial facilities, a waste handling firm, and a municipality) maximizes resources utilization and minimizes pollution by having interdependency amongst each entity's by-product (Agarwal and Strachan 2006). Swayed by this model, several industrialized countries have and are taking steps to follow suit in an attempt to gain environmental, economic and social benefits or what is referred to as a sustainable development. Mirata (2004) noted that in order to develop a successful eco-industrial park, it is imperative to assess the performance of its sustainability from a system-wide perspective. There are methods available that have been proposed and/or used to do so. Most of these methods have been used to conduct comparative analysis, and not an all-inclusive assessment to outline the environmental, economic and social benefits. Korhonen and Strachan (2004) argued that it is important to assess not only the physical aspects and flows of a given project, but also the effects that management approaches have on them as well. They also highlighted the criticalness of tying the physical flow analysis to the analysis of social and economic effects.

2.2 Dynamics of Renewable Energy

The majority of people have misperceptions of the basic dynamics of renewable energy resources, especially the accretion of greenhouse gases (GHGs) (Moxnes and Saysel 2008). These misperceptions resulted in climate change polices that appeared on the surface to minimize the GHGs, but in reality they only address the environmental impact and neglect other interdisciplinary systems. From a system dynamics stand point, this misperception is directly tied to an inability to model CO_2 accretion as stated by Moxnes and Saysel (2008):

> *... Even people who know that CO_2 or GHG emissions can lead to climate change and who think that political actions are needed, may come to favor policies that fall short of reaching their intended goals...*

Sterman (2011) argued that due to the narrow boundaries of our mental models, they tend to focus on the short span, and are incapable of taking into account dynamics of a system which is inclusive of the environmental, economic, social and functional systems. These dynamics are habituated by multiple feedbacks, time delays, accumulations and nonlinearities which are difficult for our simple mental model to recognize and understand. Sterman (2011) discusses techniques that can help understand the behavior and the dynamics of a system

> *... Stocks, flows and accumulation, pictures of bathtubs with tap and drain (or, better, animations and simulations), help people recognize the presence of important accumulations and understand how the behavior of a stock is related to its flows ...*

Sterman (2000, ch. 11) also suggests that scenarios and simulations should not be based only on the technical and operational processes that produce GHGs, but should also take into account time delays of their inner systems, and their impacts on the system as a whole. These include delays in the dissemination of information, changes of opinion, legislation implementation, agreements… etc.

One example of using such a methodology in a similar complex issue is a research done by Marzouk and Azab (2013), where they used system dynamics concept and STELLA software to model and simulate the problem at hand. Their research evaluated the impacts of two options in managing construction and demolition wastes (CDW). It focused on recycling versus disposal, and simulated different policies and regulations that intended to minimize disposal on one hand, and boost recycling activities of CDW on the other hand. Using causal loop diagram to describe the several variables in their research, they concluded that imposing regulations to recycle CDW is far more beneficial and effective in reducing global warming potentials (in terms of CO_2) than disposal in landfills.

2.3 System Dynamics Suitability

Some researchers argued that system dynamics has various limitations with respect to operational issues, nevertheless, it is well suited to simulate multidisciplinary problems. A research done by Winz et al. (2008) discussed the pros and cons of using such a methodology in the evaluation of an integrated water resources management problem. They conducted four case studies and concluded that this methodology

> *… provides a well-grounded, flexible and realistic approach to identifying and dealing with inherent uncertainties in water resources management. Hence, it prospectively*

> *provides a critical tool in adaptive management applications, assisting in derivation and ownership of realistic visions for water resources management, and the development of strategies that must be adopted to achieve these goals …*

Part of their findings indicated that the benefits of system dynamics approach include the ability to meaningfully simulate future system's behaviors, and to improve system effectiveness by continuous performance monitoring. They also noted that these benefits are maximized if stakeholders actively participate in defining the problem, formulating the model, identifying the variables, developing the relationships between them, and successfully implementing the SD recommendations.

Where climate change and global warming subject is discussed using SD models, one finds that there is a transition from discussing the modeling results of such a complex issue, to discussing and identifying SD model's sources of strengths or perhaps weaknesses. Ransers (2000) noted that the strength of a system dynamics model lies within its basic tools. These tools comprise of the 1) system causal structure, 2) the addition of unquantified important system variables, 3) usage of a reference mode, and 4) identification of system influence points. Of utmost importance of these tools, are the influence points, where Ransers offered seven suggestions to reach a sustainable stage in the areas of energy, resource management, education and eco-efficiency. It appears that these suggestions have two main focal points, reducing birth rates and fiscal/environmental policies that either encourage better practices or discourage damaging ones.

2.4 Eco-Industrial Projects Assessments

Kurup et al. (2005) proposed a method to assess potential benefits of eco-industrial projects. They argued that this method can assist those who make decision to measure the sustainability effects of an eco-industrial project on its region. The method establishes indicators based on cost-benefit accounting of the subsystems involved. These indicators identify and record economic, social and environmental gains in much better fashion. They pointed out a need to select a practical number of indicators that would reveal the major effects on a project, and cautioned against temptation to select the ones that might misrepresent the overall performance. Difficulties in measuring many indicators in financial terms were emphasized, thus they advised to quantify and rank them where feasible. The indicators developed by Kurup et al. (2005) are as follows:

1) Economic Indicators - generate local business opportunities, generate capital works, sales, profit, wages paid, taxation revenue, tangible environmental costs, transport costs

2) Environmental Indicators - land use, biodiversity, energy consumption, water consumption, air, land and water emissions, material consumption

3) Social Indicators - job creation, job security, skill level, health and well-being, community stability, education standards, level of community services, crime rates, sensory stimuli (such as, aesthetic or visual, noise, dust and odor)

For the economic indicators, Kurup et al. (2005) noted that direct costs by themselves are not a good measure of total waste disposal, and advised to incorporate cost of raw material loss and their replacement, the cost of labor used in collection and transfer, the cost of equipment used in waste treatment, and the cost of managing the system. The environmental indicators should reflect the potential short and long term impacts on the overall project, which can be challenging to quantify. Therefore, they suggested to list and rank them from minor to major. As for the social indicators, they argued that it is difficult to quantify them, and suggested to list and rank them as well with possibly positive and negative notations.

CHAPTER 3
MODELING OF A SUSTAINABLE UTILITY COMPLEX

3.1 Sustainability Concept

Since the advent of a global, market-based economy, it has become clear that vast amounts of commodities are being produced, distributed, and consumed. However, economic growth and development have at times been at the expense of the environment and the quality of life of groups and individuals. Over the past three decades, there has been increasing concern for the well-being of the environment and the conservation of natural resources. As the *Global 2000* report noted, "*If present trends continue ... serious stresses involving population, resources, and environment are clearly visible ahead. Despite the greater material output, the world's people will be poorer in many ways than they are today.*" (Barney 1980)

Clearly, the recognition that the global market system is putting a major strain on the socioeconomic and ecological systems of the planet has resulted in a demand for sustainable forms of development (Clark and Munn 1986). Since the 1980s, sustainable development has been regarded as the appropriate mechanism by which two opposing ideologies, economic development and environmental conservation, are brought together to create a more holistic approach to the advancement of society. In 1980, the term "sustainable utilization of resources" was noted in the World Conservation Strategy. The World Conservation Strategy had three principal aims, which were to maintain essential processes and life support systems, to preserve genetic diversity, and to ensure sustainable utilization of species and ecosystems (IUCN 1980). In 1987, the concept of sustainable development gained further attention in the *Brundtland Report*, entitled "*Our Common Future*," where sustainable development was defined as, " ... *meeting the needs of, and aspiration of, the present generation without compromising the ability of future generations to meet their needs"* (WCED 1987). Another commonly used definition of sustainable development, which has been adopted by the International Union for the Conservation of Nature (IUCN), is the type of development which improves the quality of life within the carrying capacity of the earth's life support system [(UCN, WWF, and UNEP 1991). These three publications have led to detailed discussions about the implications of sustainable development as an important paradigm for the twenty-first century, from both academic and policy-making perspectives. Unfortunately, the details of this new paradigm are still unclear in terms of developing measures to examine sustainability and models to achieve sustainable development. Also, there are many different approaches to understanding and implementing sustainable development, as described in the following paragraphs. Sustainable development has evolved from philosophical concerns about mankind's responsibility for nature (Passmore 1974), to locally and nationally based environmental groups demanding that more attention be paid to the environment (Lowe and Goyder 1983). From this environmental point of view, sustainable utility complex can be seen as the bridge between economic growth and environmental protection.

3.2 Interdependent Systems and System Dynamics

A sustainable municipal utility complex consists of three interdependent systems. 1) Environmental System defined as the system that includes the air, water, soil, and all other natural resources as well as all living organisms that are affected and/or used by the utility complex 2) Economic System defined as a system that includes economic and financial aspects of the locality where the complex is located, and 3) Social System defined as a system which constitutes the social, cultural, health-related aspects that are inherent in our society. These systems interact with each other dynamically in what is referred to as system dynamics. The term “dynamics” in system dynamics refers to a system situation that is changing with time. Dynamics is also interpreted as changes in the state of a system responding to changes in input variables. This understanding of dynamics, along with the definition of a system, leads to the definition of system dynamics as: “the mathematical modeling of a combination of system components so as to solve a set of equations which represent the dynamic behavior of the system and which can be solved to determine the response to various types of stimuli’ (Doebelin 1972). System dynamics was developed at Massachusetts Institute of Technology during the 1950s by Jay W. Forrester. He developed a philosophy leading to a systems viewpoint and a set of mathematical techniques for simulating complex, nonlinear, multi-loop feedback systems. The first system dynamics model applied to general management problems addresses the problems of inventory fluctuations, the instability of the labor force, and falling market shares (Forrester 1961). The primary assumption of the system dynamics paradigm is that the dynamic tendencies of a complex system arise from its causal and feedback structure. That is, a system is structured based on the causal relationships and feedback loops formed by the components in a system.

The element in the system structure that represents the system is referred to as the state variable. The overall system dynamics model can be simply generalized using the state variable, input variables, output variables, and the measures of the effectiveness of the system, as shown in Figure 3.1. In the Figure, the dynamic system responds to inputs that generate various performance measures of the system. The feedback structure and causal relationships exist in the dynamic system, which is represented by state variables, and determines the type of reaction to the input variables.

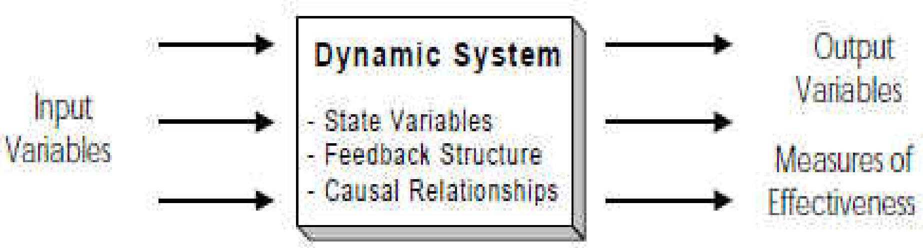


Figure 3-1. General System Dynamics Model (Drew 1996)

3.3 System of Systems Analysis

The sustainability assessment analysis of a utility complex from a system of systems approach falls in one of three categories: a) monetary modeling such as cost effectiveness analysis and cost benefit analysis, b) risk assessment modeling such as comparative risk assessment, c) multiple criteria decision modeling such as multi attribute utility theory, linear additive weighting, and fuzzy logic theory. A brief description of each of these types of models or analysis is presented in this section.

3.3.1 Monetary Analysis

3.3.1.1 Cost Effectiveness Analysis

A cost effectiveness analysis is typically used to compare different alternatives that achieve the same objective so that the least costly method of achieving the objective is reached. If several alternatives were developed for a system to comply with certain criteria, then a cost effectiveness analysis could be performed to select the alternative with the least cost. The analysis combines costs that occur at different times (such as one-time capital costs and annual operation and maintenance costs) by converting them all to a present value using an established discount rate. Thus an equitable comparison can be made among all alternatives. This type analyses alternatives that are only included in the evaluation if they can meet a certain objective.

A cost-effectiveness analysis for a proposed regulation can be calculated by dividing the annualized cost of the regulatory alternative by a measure of its effectiveness. EPA’s office of Policy, Planning and Evaluation states, “That measure may range from the amount of the reduction in pollution to the ultimate improvements in human health or the environment. Each measure has advantages and disadvantages: 'pounds of pollution removed’ is the easiest to calculate across a broad range of regulations but ignores wide differences in pollutant toxicities and dilutions, ‘units of exposure avoided’ may require sophisticated dispersion models, and ‘statistical lives saved’ requires a detailed understanding of population exposure and dose-response relationships. In general, the measure of effectiveness used should be as close as possible to the final effects thought to result from the regulation” (EPA, 1991). The cost effectiveness analysis results in determining the least costly method for achieving the specified goals.

3.3.1.2 Cost-Benefit Analysis

A Cost-Benefit Analysis (CBA) includes a number of techniques used together to quantify the costs and benefits typically associated with legislation, regulations, or policy such that a comparison of alternatives can be made on the basis of incremental and total costs, risks, and benefits. The analysis does not specify to which people the costs and benefits apply (EFAB and EFC, 1999). Using CBA, it is possible to appraise the expected impacts a project will produce in measured economic terms to balance gains and losses that take place at different times by converting them to a single value at the present time (Munier, 2004). One of the difficulties of using a CBA is in determining the value of benefits, especially benefits that are intangible. Several methods have been devised to establish these values (Munier, 2004).

The Office of Management and Budget (OMB) states, "In choosing among mutually exclusive alternatives, benefit-cost ratios should be used with care. Selecting the alternative with the highest benefit-cost ratio may not identify the best alternative, since an alternative with a lower benefit-cost ratio than another may have higher net benefit" (OMB, 1996).

3.3.2 Comparative Risk Analysis

Comparative Risk Ranking or comparative risk analysis is a management procedure used to prioritize environmental and social issues that have undergone formal risk assessment (EFAB and EFC, 1999). Risk assessments are often used in assessing human health or environmental risks which are calculated for a no action alternative and compared along with costs to several alternatives. The risks for the various alternatives are calculated and ranked. The advantage of such a system is the resulting numerical ranking of the projects in terms of "statistical statements of the probability of death, injury, or damage" (EFAB and EFC, 1999). Comparative risk ranking allows an ordering of projects by the priority in which they should be addressed or in how best to allocate limited funds among projects on the basis of risk. Although comparative risk ranking is useful in prioritizing projects on a risk basis, it requires that a formal risk assessment be conducted on the projects under consideration. Formal risk assessments require time to address each project, money to perform the assessment, and experts in toxicology and risk assessment analysis.

3.3.3 Multiple Criteria Decision Analysis

The types of analyses described before are useful for determining if the benefits of a project outweigh the costs or if one alternative is preferred over another to achieve a given objective. However, decision makers are faced with an additional problem. The situation they often face is one of a limited budget to implement all of their projects. They can perform cost effectiveness analyses to determine the best alternative and they can perform cost-benefit analyses to demonstrate that the project benefits outweigh the costs, but the issue they often encounter is that they have more justifiable projects than they have budget. The tools that these decision makers need are those that help them to determine which of these justifiable projects are the most sustainable. In other words, which projects are most sustainable in addition to providing the most benefit? To make this determination, they need a tool to prioritize their projects in a manner, consistent with established criteria, that is satisfactory to all stakeholders (including ultimately the public, which is typically the source of funding for such projects).

According to Satterstrom Linkov, “A systematic method of combining quantitative and qualitative inputs from scientific studies of risk, cost and cost-benefit analyses, and stakeholder views has yet to be fully developed for environmental decision making” Linkov, et. al., 2006). More integrative decision analysis processes such as multiple criteria decision analysis may better serve decision makers than the models described above.

Multiple criteria decision analysis “describes a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter” (Belton and Stuart, 2002). This analysis facilitates understanding of the problem and uses the priorities and values of the decision makers to take the most appropriate course of action. It does not relieve the decision maker from the requirement to make a difficult decision; rather, it provides a structure within which decision makers and stakeholders express their values and priorities to each other, resulting in a better understanding of the problem, potential solutions, and areas in which different stakeholders agree. Many times a course of action results from the process that was not originally considered that reflects a compromise of the stakeholders. This analysis approach “… integrates common sense with empirical, quantitative, normative, descriptive, and value-judgment-based analysis” (Haimes, 2005). It is supported by data management procedures, modeling methodologies, optimization and simulation techniques, and decision making approaches for the ultimate purpose of improving the decision making process (Haimes, 2005). According to Dodgson (2000), the main role of these modeling techniques is to “deal with the difficulties that human decision-makers have been shown to have in handling large amounts of complex information in a consistent way… involves breaking a problem into more manageable pieces to allow… easier analysis and then of reassembling the pieces to present a coherent overall picture to aid in thinking and decision making." As a set of techniques, the multi criteria decision modeling provides different ways of disaggregating a complex problem, of measuring the extent to which options achieve objectives, of weighting the objectives, and of reassembling the pieces" (Dodgson et al., 2000).

3.3.3.1 Multi Attribute Utility Theory

According to Doumpos (2002), multi attribute utility theory "has been one of the cornerstones of the development of multi criteria decision analysis and its practical implementation. Directly or indirectly all other approaches employ the concepts introduced by the utility theory" (Doumpos, 2002). This theory involves defining decision makers' preferences by creating a utility or value function which includes the various separate criteria which are used for making the decision. The value or utility of the independent criteria are summed up to obtain a single value for the option or alternative. This value is compared to the results from the analysis of other alternatives in order to select the one with the greatest utility for the decision maker. Application of multi attribute utility theory to helping decision makers with complex multi-criteria decisions has developed over the years since the initial theoretical work on determining a mathematical function to describe the overall utility or value of specific criteria to include the use of performance matrices, and determination of the independence of the criteria being used. Dodgson (2000) states, "Although well-regarded and effective, in its most general form it is relatively complex and best implemented by specialists on major projects where time and expertise are both necessary and available" (Dodgson et al., 2000).

3.3.3.2 Linear Additive Weighting

The simple linear additive model can be used only if the criteria are preferentially independent of each other and if uncertainty is not formally built into the model. This method combines the score for each alternative and the weighting for each criterion by multiplying the two together and summing the values for each alternative. The resultant scores for the alternatives are compared to determine the preferred alternative (Dodgson et al., 2000). This method appears to be the same as simple additive weighting methods (also referred to as weighted linear combination or scoring methods) which are based on the concept of a weighted average. The decision maker directly assigns weights of relative importance to each attribute which according to Malczewski (1999) are multiplied “by the (scaled) value given to the alternative on that attribute, and sums the products over all attributes. The alternative with the highest overall score is chosen” (Malczewski, 1999).

3.3.3.3 Fuzzy Logic Theory

The field of fuzzy sets is a relatively recent response to account for the imprecision associated with many decision contexts. Fuzzy sets attempt to deal with our naturally imprecise language. An alternative may be described as “somewhat” significant versus just “significant.” Fuzzy arithmetic attempts to capture these qualified assessments using membership functions. Alternatives can be assigned membership in a set of “significant” options with a degree of membership ranging from 0 to 1. Models are developed to aggregate the fuzzy performance levels using weights that are also sometimes represented as fuzzy quantities.

A synthesis of fuzzy logic and adaptive resonance theory (ART) is fuzzy ART. It provides a tool to cluster patterns according to their common characteristics. This permits grouping patterns into similar clusters that can be used later for performance indicators. Using the fuzzy ART algorithm, patterns are mapped to a group of categories out of which indicators are selected. A more detailed description of fuzzy ART is described in subsequent sections.

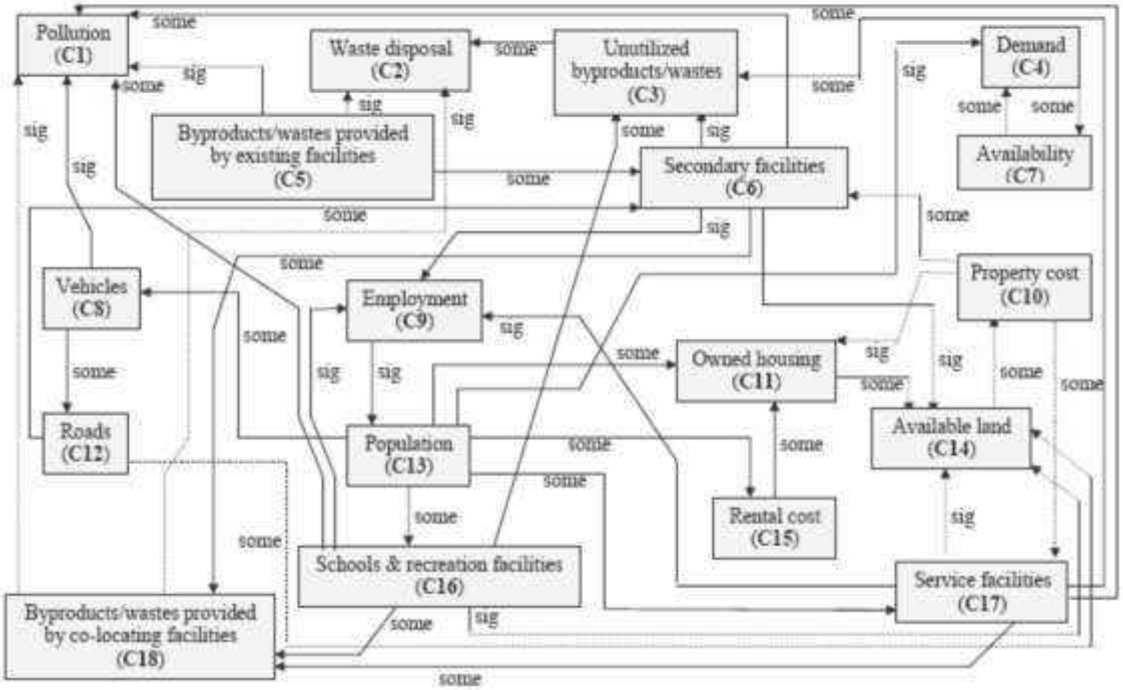
3.4 Modeling Approach

The proposed modeling approach utilizes a multi criteria decision analysis based on system dynamics modeling using Vensim program. The advantages of this approach are: 1) it covers direct impacts, and also takes into account indirect effects or interaction between impacts 2) built on the structures of qualitative description used in everyday language 3) method to define the vague or ambiguous nature of fuzzy set 4) easily addresses certain data set issues such as missing values, overlap of common information, complex and nonlinear interdependencies.

This model is similar to Fons's fuzzy cognitive map which is a type of neural network model that offers a means to model interrelationships or causalities among elements within the model as presented in Figure 3.2. Fuzzy cognitive map is a newer form that quantifies the interrelationships among elements of a network in a non-binary way, such as when linguistic hedges and quantifiers are used to characterize the causalities that are based primarily on linguistic information. (Fons et al. 2004). Using this model, an adjacency matrix is created.

The adjacency matrix is a performance matrix congregated from performance measures collected from the input variables on the environmental, economical, and social subsystems. A numerical analysis is conducted on the performance matrix to determine the preferred alternative. The analysis involves weighting to define the relative value or importance of each criterion. As referenced by Dodgson et al., 2000,

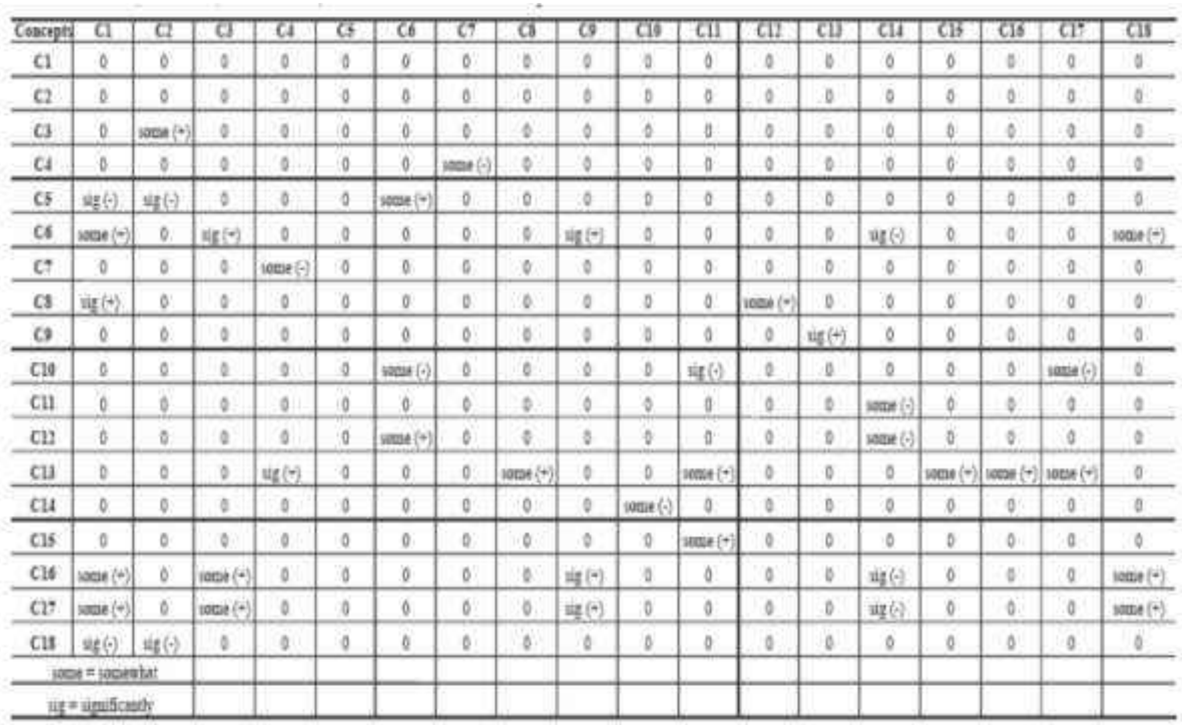
> "*The most common way to combine scores on criteria, and relevant weights between criteria, is to calculate a simple weighted average of scores. Use of such weighted averages depends on the assumption of mutual independence of preferences. This means that the judged strength of preference for an option on one criterion will be independent of its judged strength of preference on another*"



C- cause and effect variables, sig- significant, some-somewhat, solid arrow: +ve causal relationship, dashed arrow: -ve causal relationship

Figure 3-2. Fuzzy cognitive map of the impacts of an eco-industrial park (Fons et al. 2004)

This matrix clearly demonstrates all direct & indirect and negative & positive impacts as shown on Figure 3.3, both can allow calculating the direct and indirect impact of any particular variable. The decision support system model requires an algorithm to assign different performance measures to different categories or clusters, similar to the use of Fuzzy Adaptive Resonance Theory (Fuzzy ART model), which is a synthesis form of fuzzy logic and ART (Carpenter et al. 1991). It is a clustering algorithm that maps a set of input patterns to a set of categories. Ishak and Al-Deek (1998) noted that fuzzy ART model provides fast, stable learning in response to analog or binary input patterns.



Concepts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0
C5	sig (-)	sig (-)	0	0	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0
C6	some (+)	0	sig (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)
C7	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	sig (+)	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	sig (+)	0	0	0	0	0
C10	0	0	0	0	0	some (-)	0	0	0	0	sig (-)	0	0	0	0	0	some (-)	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0
C12	0	0	0	0	0	some (+)	0	0	0	0	0	0	0	some (-)	0	0	0	0
C13	0	0	0	sig (+)	0	0	0	some (+)	0	0	some (+)	0	0	0	some (+)	some (+)	some (+)	0
C14	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0	0
C16	some (+)	0	some (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)
C17	some (+)	0	some (+)	0	0	0	0	0	sig (+)	0	0	0	0	sig (-)	0	0	0	some (+)
C18	sig (-)	sig (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
some = somewhat																		
sig = significantly																		

Some -: negative somewhat, some +: positive somewhat, sig -: negative significantly, sig+: positive significantly

Figure 3-3. Adjacency "Performance" Matrix of an eco-industrial park (Fons et al. 2004)

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Sustainability Indicators

As the three interdependent systems interact dynamically within the utility complex, each (environmental, economic, and social) performs and produces certain outputs, which can be represented by their respective performance indicators. Indicators should have the following attributes: be monitor-able or track-able over time, measurable, accurate (reliable, valid), based on demonstrated links between environment and health, tied to environmental, social, and economic objectives, useful and understood by diverse populations, accessible at different levels (e.g., state, county, municipality), and informative to the public and to responsible agencies.

The definition of sustainability indicators is an important step, as the selection of sustainable solutions is based on these indicators. A sustainable solution means limited use and limited degradation of resources through harmful emissions, at the same time avoiding the export of the problem in time or space. As described before, it is possible to distinguish three types of resources: economic, environmental and social. Therefore, the same categorization is used for the indicators including one additional category, namely the functional indicators as shown on Figure 4-1. While the economic, environmental, and social indicators give insight into the efficiency of the solution, the functional indicators determine the effectiveness of the solution. This last group, the functional indicators, can therefore be seen as constraints, because it is no use applying a technology efficiently if in the perception of the end user this does not provide a satisfactory solution.

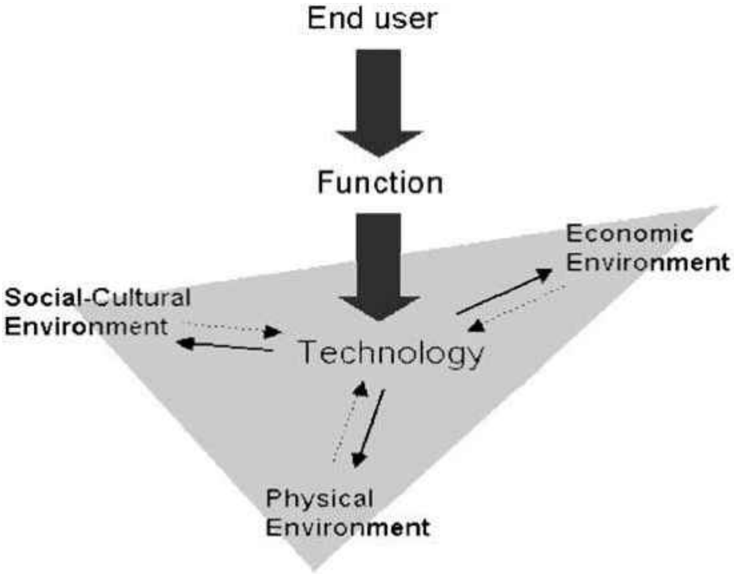


Figure 4-1. Environmental, economic, and social interaction (Balkema et al. 2002)

A detailed description of the sustainability indicators is as follows:

4.1.1 Functional Indicators

Functional indicators define the minimal technical requirements of the solution. For instance, for wastewater treatment this may be the minimal required effluent quality. Additional indicators may be adaptability (possibility to extend the system in capacity, or with additional treatment), durability (lifetime), robustness (ability to cope with fluctuations in the influent), maintenance required, and reliability (sensitivity of the system to malfunctioning of equipment and instrumentation).

4.1.2 Economic Indicators

Economic indicators are often decisive when choosing a technology in a practical situation. Commonly used indicators are, of course, costs of investment, operation, and maintenance. Derived indicators are for instance affordability, cost effectiveness, and labor.

4.1.3 Environmental indicators

Although sets of sustainability indicators used in literature differ, there seems to be a consensus on the environmental indicators. Optimal resource utilization is used by all as an indicator, particularly addressing water, nutrients, and energy. In addition required land area, land fertility, and biodiversity are mentioned in several studies. Another group of environmental indicators is emission oriented, for instance the quality of effluent and sludge, combined sewer overflows, and gaseous emissions.

4.1.4 Social indicators

Social indicators are hard to quantify and are therefore often not addressed in literature. However, these indicators play an important role in the implementation of technology. This is especially the case, when the end-user is directly involved, like in water use, sanitation, and small-scale on-site treatment. Indicators in this category are for instance:

a. Institutional requirements: Different wastewater treatment systems will require different regulations and control mechanisms. These requirements should fit in the existing institutional infrastructure of the country or region.

b. Acceptance: In different cultures, people will have a different perception of waste and sanitation, resulting in different habits. New sanitation concepts, including different toilet systems, may encounter social or cultural difficulties in the implementation. For instance: the need to explain to visitors how to use the separation toilet was one of the reasons to remove these toilets from the houses of an ecological village (Fittschen & Niemczynowicz, 1997).

c. Expertise: The selected technological solution requires a certain level of expertise for installation and operation. If the expertise is not locally available it may be gained through import or training.

d. Stimulation of sustainable behavior: Sustainable behavior can be stimulated by tailoring the technological design such that sustainable behavior is the most convenient option. Other ways to stimulate sustainable behavior are increasing the end-user's awareness, participation, and responsibility.

All these indicators can be quantified, either through measurements, cost calculations, or enquiries. However, in a rapid assessment many of these indicators may be estimated using averages, and indications of the influence of a technology on a certain indicator. For instance, a composting toilet may have a potential advantage for 'stimulation of sustainable behavior' as no water is used and the end-user recycles the compost locally. However, a potential disadvantage may be 'acceptance' because the end-user may perceive sanitation without water unhygienic and may not be willing to use the compost in his/her garden. In this way, these indicators can be used as go or no go decision variables in optimization. Meaning that more than one indicator can set the optimization procedure to only select technologies that have a potential advantage or to not select technologies with a certain potential disadvantage.

4.2 Mathematical Analysis and Computer Simulation

The system equations formulated from the mathematical model are solved to quantify the system variables. The solution is facilitated through analytical solution method which is the basis of the computer simulation that generates each estimate using a discrete or a continuous formulation. Assuming a system that reaches equilibrium at some time, the variations in the system over time can be thought of in two phases – the phases before and after the equilibrium point – in which the values of system variables do not change. Analysis concerning the former phase is called a “transient analysis.” In transient analysis, time dependent equations for variables are derived to configure the system’s behavior until reaching the equilibrium point. This derivation is implemented by solving a set of differential equations. On the other hand, the analysis considering the latter phase is called a steady-state analysis. The solution of steady-state analysis is easily obtained by setting the values of rate variables to zero. This method is based on the fact that, beyond the equilibrium point, rate variables do not affect the level variables, and as a result, the values of the level variables remain constant. The steady-state solution is often incorporated into the transient solution, and causes the transient solution to be a function of time, constants, and variables at equilibrium. The form of the transient solution varies in accordance with feedback polarity, the order of the feedback system, and the type of system. Whether or not a system reaches equilibrium depends on the model structure, not on the adjustment of parameter values. A change in parameter values only affects the magnitude of the behavior, but does not impact the pattern of behavior. In a case where a model shows a different time-dependent pattern from the real system, it should be remedied not by data manipulation, but by changing or reconstructing the model’s structure.

CHAPTER 5
MODEL DEVELOPMENT

5.1 Municipal Utility Complex Model

The decision makers who make policies, plan, and invest in a municipal utility complex are assessing its sustainability and basing their decision only on its environmental and/or direct cost impacts. Their policies need to be analyzed using a scientifically or logically reasonable methodology based on a broad understanding of the whole structure of the utility complex system and its interdependencies and relationships with other systems. In addition, they lack a decision support system that is practical and can be utilized easily and flexibly in the decision making processes.

In this approach, municipal utility complex "differs both from current economic practice, where only phenomena that can be quantified and are captured in the price structure are deemed to matter for most resource allocation and consumption decisions, and from current environmental regulation practice, which emphasizes non-systemic, single dimensional definitions of, and responses to, environmental perturbations" (Allenby 1992).

Although a municipal utility complex is built with synergistic opportunities for integration of processes of a wastewater treatment plant, a resource recovery facility (aka waste-to-energy (W2E) or incineration facility), a material recovery facility (MRF), and a landfill; engineers tend to use traditional sustainability assessment methods to assess the life cycle (LCA) of each system's process over time. They are not necessarily incorporating a system dynamics assessment based on interaction the sub-systems (see Figure 1-1).

How systems within the complex should interact, as well as the resulting strategies cover a wide range of features. While some researchers merely refer to connecting material and energy flows between the sub-systems (S. Manahan 1999 / Schön & Kunze 1999), others go far beyond that, addressing integration into the surroundings, construction technologies and the management (Lowe et al. 1998). Others additionally include the social factor, pointing out the fact that "Valuing natural resources means also valuing human resources" (Cohen-Rosenthal et al 1998), thus arguing in line with the three components of sustainability outlined in the Agenda 21 (UNCED 1992) - the economic, ecological and social components (Côté & Cohen-Rosenthal 1998).

5.2 Reference Modes

Four reference modes are selected to depict the multi-dimensional patterns of behavior for this system arising through the nonlinear interaction of the subsystems with one another. Data from 1970 to 2011 is used for reference and validation on the first three modes (population, employment and personal income) based on an existing MUC facility in Pasco County, Florida that has the same structural sub-systems within the County. The fourth mode (landfill remaining capacity) has projected data from 2003 forward. The MUC facility was built in 1989 and put into service in 1991 and operational to date, data was collected approximately 20 years prior to gain a better behavioral understanding.

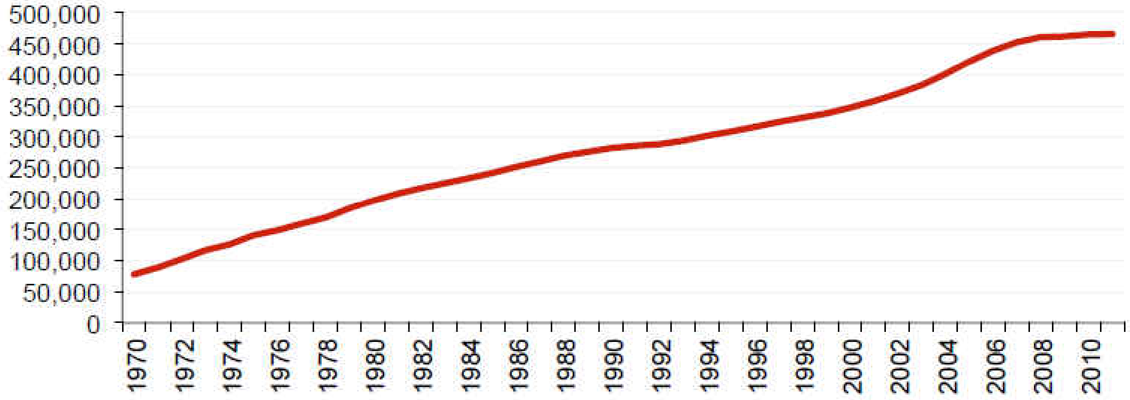


Figure 5-1. Population trends in Pasco County, FL
Population grew by 497% from 1970 to 2011
(U.S. Department of Commerce. Bureau of Economic Analysis, REIS Table CA30)

Population growth, employment, and personal income are commonly observed and easily measured reference modes of behavior as shown on Figures 5-1, 5-2, and 5-4 respectively. From 1991 to 2011, the historical modes of behavior in this dynamic system are S-shaped growth.

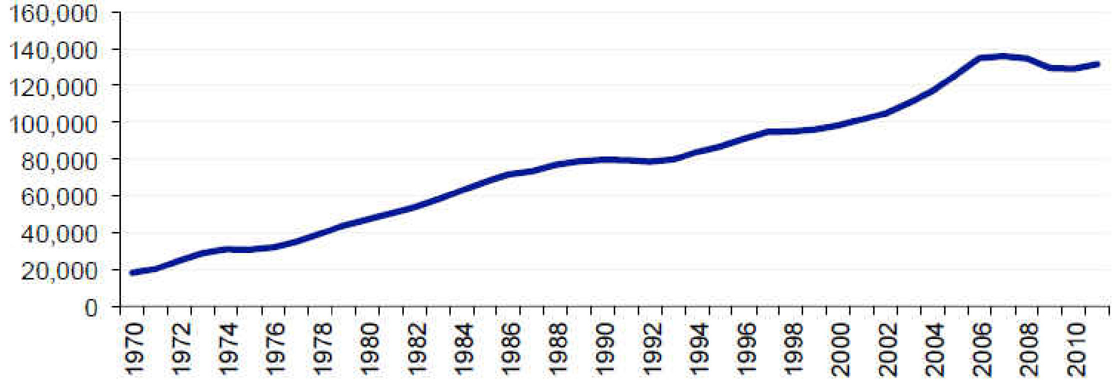


Figure 5-2. Employment trends in Pasco County, FL.
Employment grew by 625% from 1970 to 2011
(U.S. Department of Commerce. Bureau of Economic Analysis, REIS Table CA30)

The shape of these curves resembles a stretched-out "S", indicating a growth exponentially at first, but then gradually slows until the state of the system reaches an equilibrium level. The system generates an S-shaped growth because of the interaction of the positive and negative loops that are non-linear within its subsystems. A more detailed explanation of this interaction is presented in more details in the model validation section.

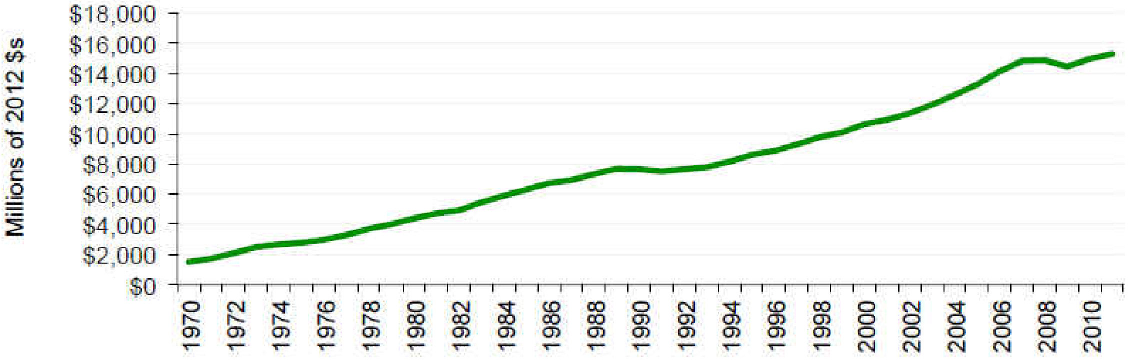


Figure 5-3. Personal Income trends in Pasco County, FL
Personal income grew by 918% (in real terms) from 1970 to 2011
(U.S. Department of Commerce. Bureau of Economic Analysis, REIS Table CA30)

Figure 5-4 shows the capacity remaining at the class I landfill at the MUC in Pasco County. Since the landfill initial capacity is constant, the shape of this curve is an exponential decay as less and less capacity becomes available through the years.

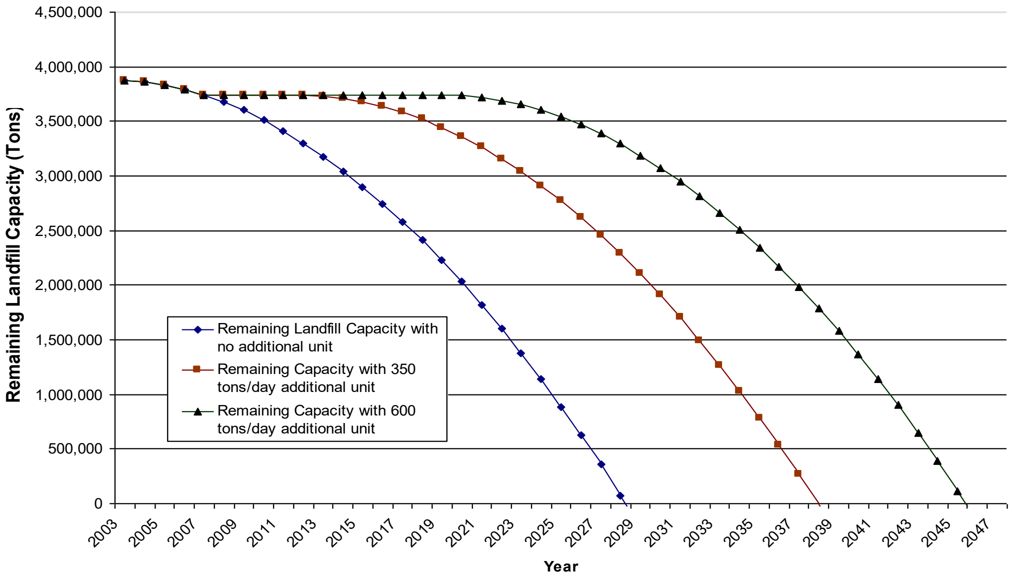


Figure 5-4. Capacity remaining for the class I landfill at MUC in Pasco County, FL (Pasco county government, utilities division, solid waste landfill report, 2003)

5.3 Identification of Parameters

The parameters used in the municipal utility complex system dynamics model represent the model boundary, and are selected to study the subsystems' feedbacks as listed in Table 5-1. This diagram summarizes the scope of the model by listing key endogenous variables, which enable us to discover the patterns of behavior created by the rules amongst them, and study how the behavior might change if we alter those rules. The model also contained several exogenous variables, which include employee productivity, tax rates and technological progress. These variables might be affected by changes in the overall system and consequent changes in the rate of economic growth, GHG emissions, and overall population, however, these feedbacks seemed likely to be small, and therefore, we assumed that they are constant and considered them exogenous variables. The diagram also listed excluded variables in order to provide important notation to the reader or user as whether this model is appropriate for their purpose.

Table 5-1 Model boundary – endogenous and exogenous variables

Endogenous variables	Exogenous variables	Excluded variables
Births	% of Ash	Environ. constraints
Building Rate	% of business	non-energy resources
consumption	% of waste combusted	
Deaths	avg. amount of solid waste generated per person/day	
Decaying Rate	Avg. Decay Rate	
Electricity Generated	birth rate	
Employed Labor	capita/house	
Employed Labor Rate	Const. Demo Debris	
Finishing Rate	consump rate	
fraction attending school	cost to build a school	
Houses in Process	CPI	
Housing Demand	death rate	
initial build up cost	exit rate	
investment	FINAL TIME	
Labor Exit Rate	govmt. spending	
Labor force	INITIAL TIME	
Landfill	initial value	
Net Migration	invest. rate in Ed	
number of businesses	labor fraction	
number of schools	net migration rate	
operating cost	rate	
personal income	rated capacity	
Population	schooled time	
Population Growth	time for waste collection	
rate of ash	time goal to fill gap	
rate of investment	time to be employed	
real GDP	time to build	
Revenue from Electricity sales	time to exit	
school graduates	unemployment rate	
Solid Waste Amount		
solid waste generation rate		

Endogenous variables	Exogenous variables	Excluded variables
Total Amt incinerated @ W2E Plant		
Total Build. Lots		
Total Houses		
Trained Labor Rate		
Unemployed Skilled Labor		
waste incineration rate		

Table 5-2 Model boundary – parameters, values and units

Parameter	Value	Type	Units
Births	birth rate*Population	Endogenous	people/Year
Building Rate	IF THEN ELSE(Total Build. Lots>Housing Demand,Housing Demand*time goal to fill gap,0)	Endogenous	house/Year
consumption	consump rate*Employed Labor*personal income*CPI	Endogenous	$/Year
Deaths	death rate*Population	Endogenous	people/Year
Decaying Rate	Total Houses*Avg. Decay Rate	Endogenous	house/Year
Electricity Generated	0.6*Total Amt incinerated @ W2E Plant	Endogenous	MWh
Employed Labor	INTEG(Employed Labor Rate-Labor Exit Rate,10000)	Endogenous	people
Employed Labor Rate	Labor force*(1-unemployment rate)/time to be employed	Endogenous	people/Year
Finishing Rate	Houses in Process*time to build	Endogenous	house/Year
fraction attending school	Population Growth*rate	Endogenous	people
Houses in Process	INTEG(Building Rate-Finishing Rate,0)	Endogenous	house
Housing Demand	Population/capita/house	Endogenous	house
initial build up cost	rated capacity*656	Endogenous	$
investment	number of businesses*rate of investment	Endogenous	$
Labor Exit Rate	Employed Labor*exit rate/time to exit	Endogenous	people/Year
Labor force	labor fraction*Population Growth	Endogenous	people
Landfill	INTEG(-rate of ash,5.7e+006)	Endogenous	tons
Net Migration	Population*net migration rate	Endogenous	people/Year
number of businesses	Population*% of business	Endogenous	business

Parameter	Value	Type	Units
number of schools	real GDP*invest. rate in Ed/cost to build a school	Endogenous	schools
operating cost	34.4*Total Amt incinerated @ W2E Plant	Endogenous	$/Year
personal income	initial value	Endogenous	$/Year
Population	INTEG (Population Growth,281937)	Endogenous	people
Population Growth	Births-Deaths+Net Migration	Endogenous	people/Year
rate of ash	% of Ash*min(rated capacity,waste incineration rate)+Const. Demo Debris	Endogenous	tons/Year
rate of investment	0.001*Population Growth	Endogenous	
real GDP	consumption+govmt. spending+investment	Endogenous	$
Revenue from Electricity sales	54.63*Electricity Generated/0.6	Endogenous	$
school graduates	fraction attending school*number of schools	Endogenous	people
Solid Waste Amount	INTEG(waste incineration rate-solid waste generation rate,0)	Endogenous	tons
solid waste generation rate	(avg. amount of solid waste generated per person/day*Population/2000)*365/time for waste collection	Endogenous	tons/Year
Total Amt incinerated @ W2E Plant	INTEG(min(rated capacity,(waste incineration rate-rate of ash)),rated capacity)	Endogenous	tons
Total Build. Lots	INTEG(-Building Rate,2e+007)	Endogenous	house
Total Houses	INTEG(Finishing Rate-Decaying Rate,100000)	Endogenous	house
Trained Labor Rate	school graduates/schooled time	Endogenous	people/Year
Unemployed Skilled Labor	INTEG(Trained Labor Rate-Employed Labor Rate,20000)	Endogenous	people
waste incineration rate	% of waste combusted*solid waste generation rate	Endogenous	tons/Year

5.4 System Conceptualization

To better understand the MUC system structures, a causal loop diagram is shown on Figure 6 to represent the relationships between systems' variables which are not necessarily linear but circular chains of cause and effect.

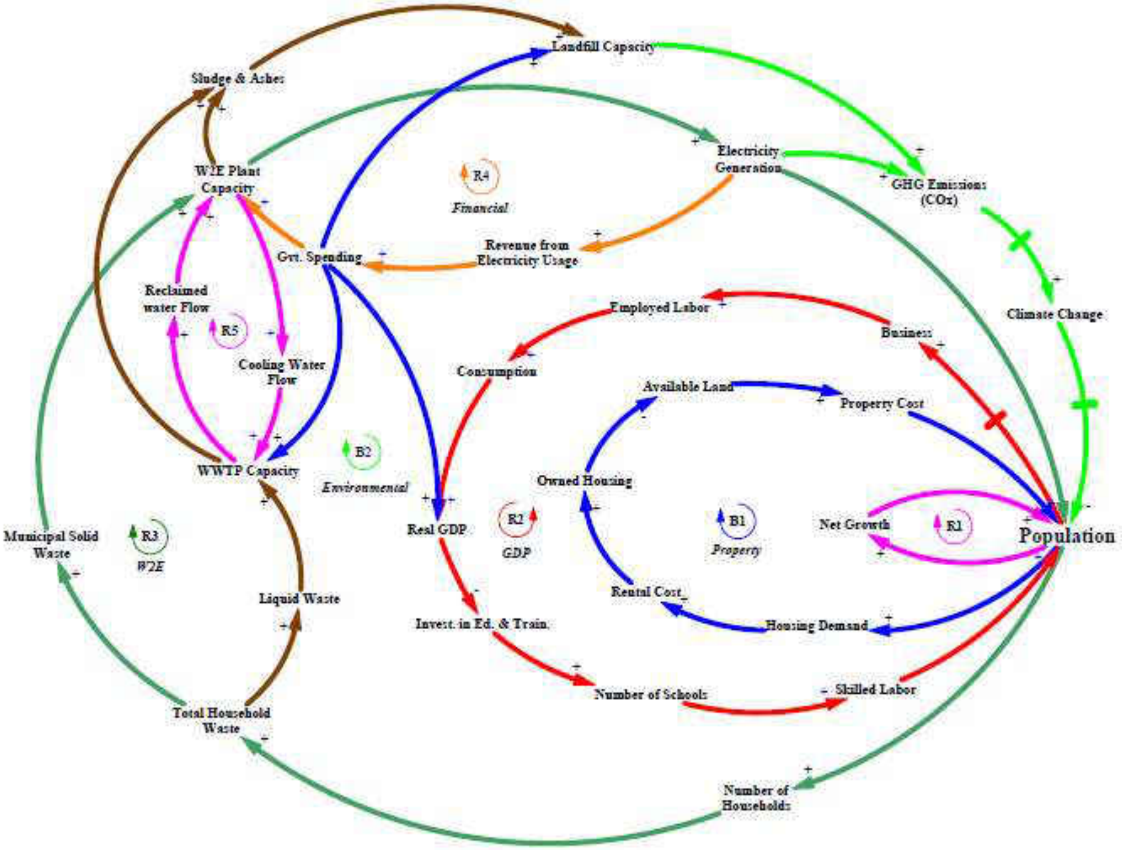


Figure 5-5. Causal Loop Diagram of a municipal utility complex

A municipal utility complex is presumably built close to metropolitan areas where a group of initial population settles in a location for its natural advantages, be they access to transportation, proximity to resources, or strategic importance. The population may then grow through a variety of positive feedbacks, including natural population growth and immigration of others attracted by the economic opportunity. Population growth is a natural result of the resources available and the resource requirements of the population. As the population approaches its capacity, resources per capita diminish thereby reducing the growth rate until there are just enough resources per capita to reach equilibrium.

To keep the causal loop diagram simple, births, deaths and immigration are totaled and the net births are presented in the net growth loop (R1). This loop is self-reinforcing as increase in net births will increase population growth which will subsequently increase the population. Growth in population will increase business activity and demand for labor, which will increase employed labor and subsequent consumption into the economy and hence increase the real gross domestic product (GDP). This population will tend to invest a fraction of the total output in education, technology and training which will require adding more schools and graduating more skilled labor. This loop is also self-reinforcing as new people require housing, new businesses require structures and labor, all require infrastructure, thus creating still more business and entrepreneurial opportunities, all these positive loops increase population as represented in the GDP loop (R2).

Growth is eventually halted by one or more negative feedbacks. As the increase population fills the land, the demand for housing increases leading to higher rental costs and encouraging home ownership and more land development. As a result, the availability and affordability of land for housing and businesses falls, slowing business formation and deterring further growth. These activities will eventually have a negative impact on the population as represented in the balancing property loop (B1).

A larger population and economic base generate more municipal solid waste leading to an increase in the incinerator capacity at the waste-to-energy (W2E) plant, which in turn generates more electricity leading to additional resource availability. All these positive loops increase population as represented in the W2E loop (R3). Increase in electricity will generate more revenue and encourage government spending on capital assets, in particular the ones contributing to generating electricity. This will create a reinforcing loop as represented in the financial loop (R4). Similarly, growth will increase liquid waste and treated wastewater or reclaimed water and the return cooling water used in the W2E chillers as represented in the reinforcing water loop (R5). Growth will also generate more pollution, and higher greenhouse gas (GHG) emissions, stressing the natural environment causing climate change and eventually limiting population growth as represented in the balancing environmental loop (B2). There are often significant delays in the action of these negative loops, which possibly will lead to overshoot and oscillation in the population.

5.5 Model Formulation

5.5.1 Net Growth Loop

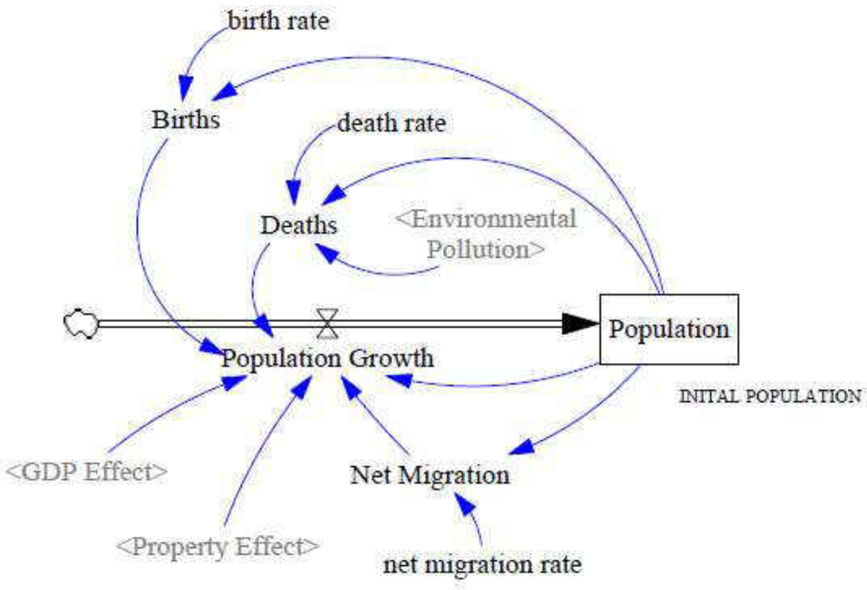


Figure 5-6. Net growth stock and flow diagram

Births and life expectancy are not the only endogenous inputs that impact population growth in an area that houses a municipal utility complex or an eco-industrial park. Factors such as environmental pollution, the gross domestic product (GDP), property availability as well as net migration all create a huge number of feedbacks that ultimately impact the size of the population as shown on Figure 5-6. This model integrates population, migration, the economy, natural resources in terms of property or land, and the environment.

5.5.2 Property Loop

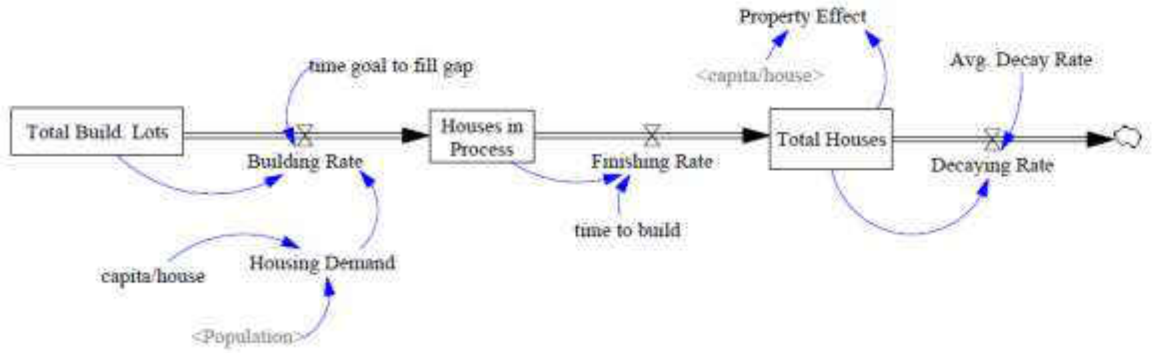


Figure 5-7. Property stock and flow diagram

The property stock and flow diagram is depicted in Figure 5-7. The model uses the rate of building as a first-order delay, which eventually results in total houses that do not immediately adjust to the amount determined by supply of buildable lots and housing demand. Rather, the total houses are modeled as a stock whose inflow is determined by the finishing rate of the houses in process and its outflow by the decaying rate of existing houses. The building rate is impacted by the time goal to fill the gap between the supply and demand for housing. Supply is equivalent to buildable lots stock, whose outflow is "building rate". Housing demand is a function of population, which is determined by multiplying the capita per house by the population. Therefore, the number of houses in process is a function of the building rate and the finishing rate. Such a stock-like nature can result in the accumulation of houses over a period of time. If building rate is greater than finishing rate, number of houses in process is accumulated. On the other hand, if building rate is less than finishing rate, number of houses in process is depleted. In this model, for the purpose of simplification, it is supposed that there is no speculative demand in the market, property owners supply all of the houses.

5.5.3 GDP loop

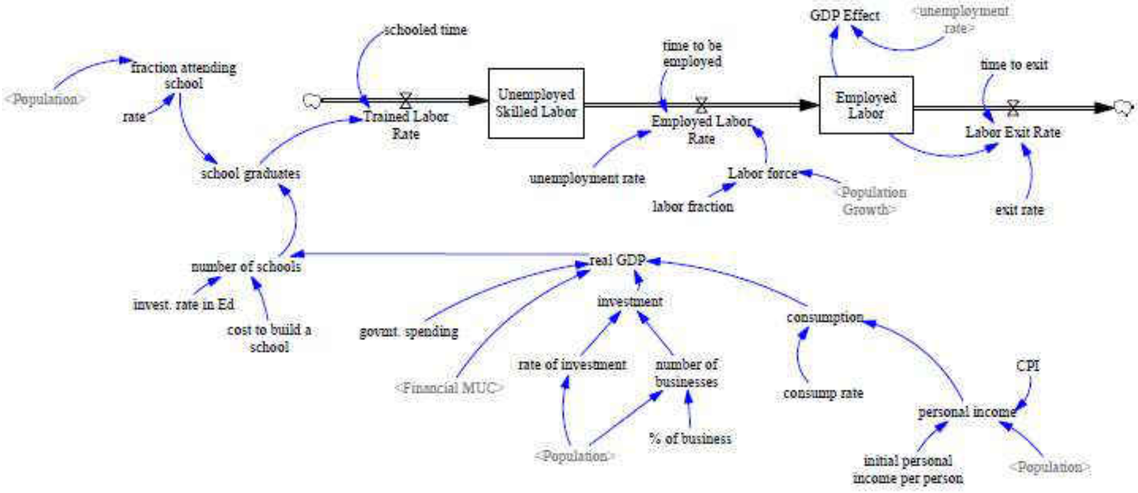


Figure 5-8. GDP stock and flow diagram

The gross domestic product portion of the model is constructed considering a small open economy, which means that the economy is strongly influenced by exogenous policies whereas the influence of its decisions is very limited. The metropolitan area is populated by an overlapping generations in which individuals live for four periods. During the first period of life, people could choose whether to study or to work. During the second and third periods of life, people just work or are unemployed and, finally, during the fourth period of life, people do not work: they are retired and they exit the labor market. Then individuals who comprise the employed labor take part in the productive sector except for the students, the retired and the unemployed people. In accordance with the decision of investing in education or not during the first period of life, the economy has two types of workers: skilled and unskilled workers. The level of skill is important because every employee receives a wage depending on it. The wages are set by the firms taking into account the production. As regards the education, it is assumed that it is expensive and everybody cannot afford it. Because of this, the government could subsidize it in order to increase the number of skilled workers in the economy and, in that way, increase the production. Likewise, all individuals consume and the fraction of wealth that is not consumed is saved. The wealth accumulated by the agents is lent to the firms. As a result, the individuals receive capital income that is valued considering the interest rate because the economy is both open and small. Finally, it is assumed that people are benefactors with regard to their offspring and they leave a bequest when they die. The productive system combines labor and capital to obtain final production that is identified with the GDP. The productive system requires two type of skill and distinguishes between skill and unskilled workers. As far as the government is concerned, it levies taxes on final production and on the income of individuals that includes labor and capital income. The public resources obtained from the taxes and the municipal utility complex are allocated by the government to get certain targets. In particular the model assumes that the government will invest in schools to increase the number of skilled labor through education, which must be thought of as an infrastructure requirement necessary to obtain the production. This public good is financed through taxes and partially by the revenue generated from the municipal utility complex (if any), implying that if the government tries to achieve other aims, then the tax rate must increase. The workers' personal income is the result of adding the capital income and the labor income. However, workers receive net income because of taxes. A fraction of the net income is consumed and the remainder is saved yielding an increase of capital. The government's actions can provoke new feedback loops if the public resources obtained from taxes are invested for boosting some stage of the productive sector or to improve workers' income. When a fraction of the public resources are used for subsidizing education, then the production progressively will improve because educated people would have higher productivity. In fact, the loop considers how the government increases the public resources from the consumption; but if these resources are invested in education then, the production grows when more educated become part of the productive system.

5.5.4 W2E Loop & Financial Loop

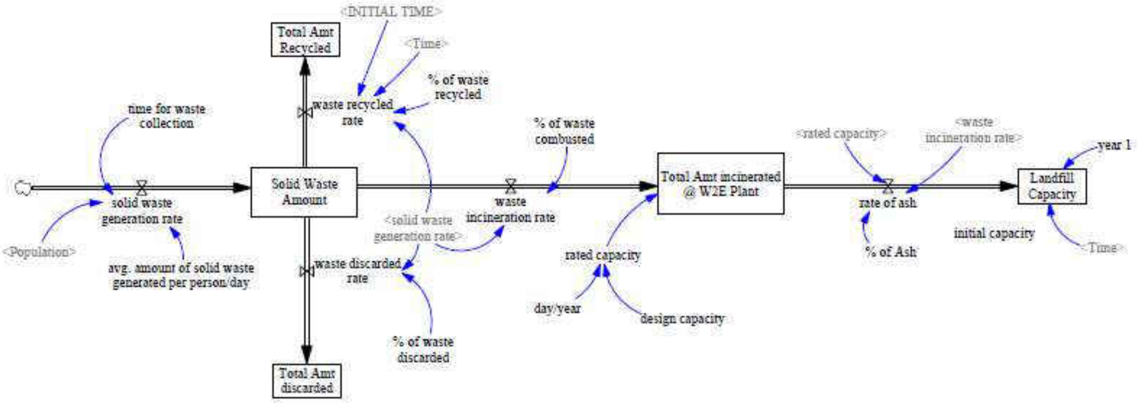


Figure 5-9. W2E stock and flow diagram

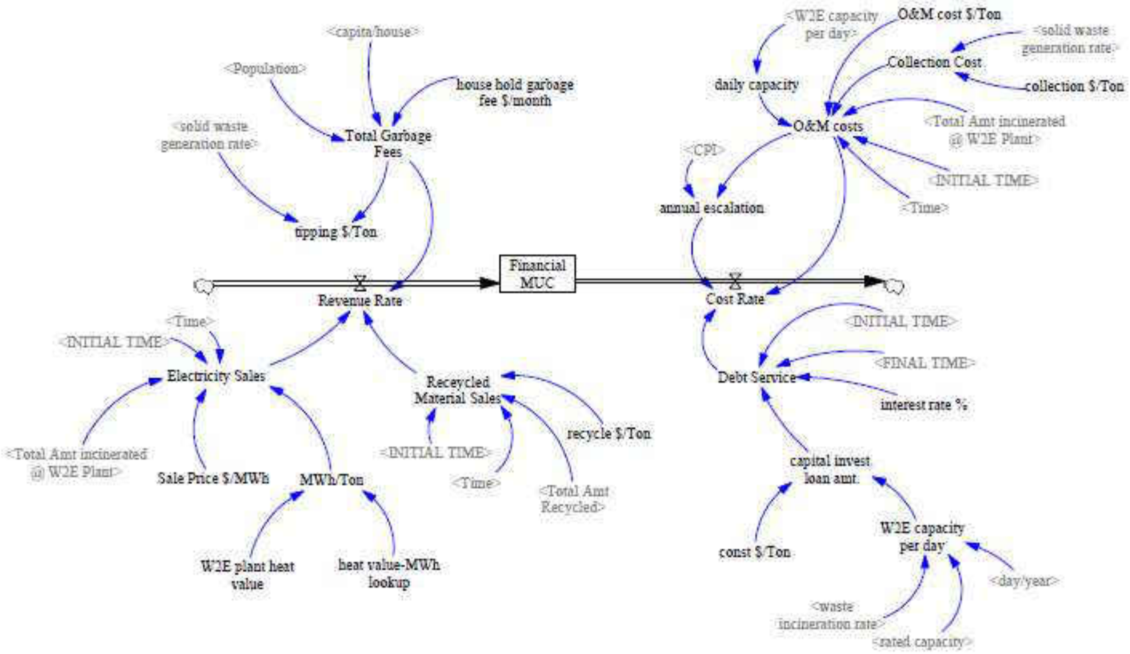


Figure 5-10. Financial stock and flow diagram

The model structure is based on the flow of municipal solid waste (MSW) management through the system. It incorporates the "downstream" sectors of consumer disposal, collection of discarded material, processing, and disposal as shown on Figure 5-9 for the W2E loop that integrates these sectors.

New MSW material enters this stock-and-flow structure from the population either residential, production or manufacturing sectors, and accumulates in the stock of solid waste based on solid waste generation rate. This stock is emptied through one of three pathways: diversion to incineration facilities, diversion to recycling facilities or discarded. Discarded material will either be diverted to composting or disposed in a landfill facility. Material from composting or recycling facilities can continue back to the production sector to be reintegrated into new products.

5.5.5 Environmental Loop

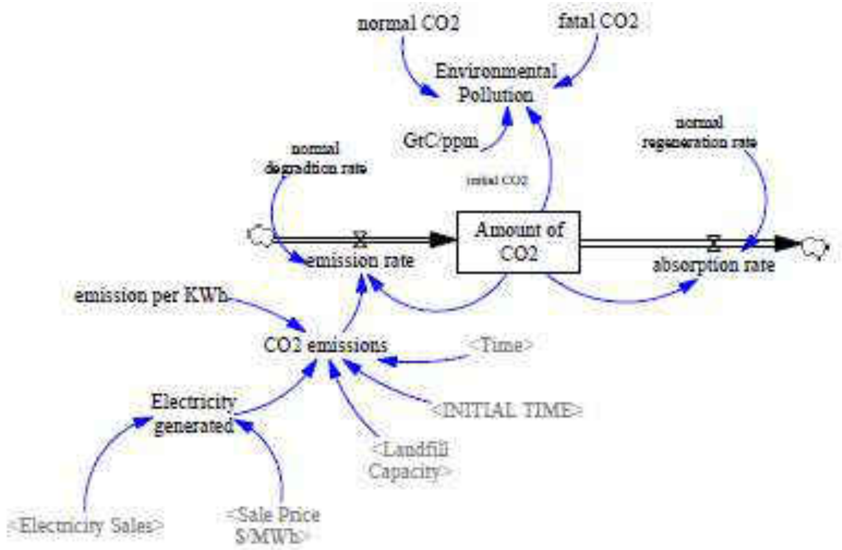


Figure 5-11. Environmental stock and flow diagram

Although the world's climate system is very complex, the dynamics of the most important greenhouse gas, CO_2, can be well approximated by a simple model (first order differential equation). The stock-and-flow diagram in Figure 5-11 illustrates the dynamics of CO_2. The stock of CO_2 in the atmosphere increases by the emissions rate and decreases by the absorption rate of terrestrial and ocean ecosystems. As long as the CO_2 emission rate (inflow) exceeds the absorption rate (outflow), the stock of CO_2 continues to increase. Only when the absorption rate equals the emission rate, the stock is stabilized. The arrow from the CO_2-stock to the absorption rate illustrates that the outflow depends on the stock (CO_2-concentration).

The differential equation analogy of the stock-and-flow diagram is

$$\frac{dS}{dt} = \mathrm{E} - a\mathrm{S}$$

where S is the stock of CO_2 measured in gigatons of carbon (GtC) above the preindustrial level, E is anthropogenic carbon emissions in GtC per year and a is the per unit absorption rate. This model assumes $a = 0.023$ per year (Moxnes and Saysel 2004). Saturation of sinks implies that a will be reduced over time and a chosen value for $a = 0.013$ per year (corresponding to a lifetime of 77 years for atmospheric CO_2).

CHAPTER 6
MODEL VERIFICATION

In order to establish the accuracy, truth or the model's reality, it is important to conduct verification analysis to uncover errors so we can understand its limitations, improve it, and ultimately use the best available model to assist in important decisions. This section describes specific procedures we followed to verify and test the suitability of this model for its purpose, uncover flaws, and improve the chances that this model will be used and useful.

All the tests listed in this chapter have been applied to verify and evaluate the system dynamics model.

6.1 Boundary Adequacy

Table 1-1 in Chapter 1 summarizes the major endogenous and exogenous variables in this model. The key endogenous variables, which enable us to discover the patterns of behavior created by the rules amongst them, and study how the behavior might change if we alter those rules are consistent with the purpose of all the major aggregates: population growth, births, deaths, labor force, employed labor, total houses, personal income, real GDP, solid waste amount, total amount incinerated at W2E plant, electricity sales, total garbage fees, O&M costs, CO_2 emissions and environmental pollution are generated endogenously. GDP is the only exogenous variable. The table also contained several exogenous variables, which include employee productivity, tax rates and technological progress. These variables might be affected by changes in the overall system and consequent changes in the rate of economic growth, GHG emissions, and overall population, however, these feedbacks seemed likely to be small, and therefore, we assumed that they are constant and considered them exogenous variables.

6.2 Structure Verification

The structural verification is of fundamental importance in the overall validation process. We have applied a two-pronged approach to structurally verify the model. First, during the construction of the model, we utilized (a) the specific case study of Pasco County's data (or available knowledge about the real system), and (b) the sub-models/structures of the existing models of the domain, as illustrated previously in the model formulation section, and the conceptual model is represented by a causal loop diagram depicted in Figure 5-5.

The net growth loop is impacted by the property, GDP, and environmental loops. These sub models are intertwined with the W2E and financial loops. The gap between electricity supplied and demanded is shortened by the increase in solid waste generated by the general population. The solid waste in turns is recycled, discarded or incinerated which generates electricity. These solid waste management types will after a delay, depending upon the type of W2E power plant being constructed, result in the electricity generating capacity. The capital together with resources will generate electricity. The landfill storage capacity acts as a limiting factor for the on-site resource availability, the generation of electricity will also produce carbon emissions.

However, only when the environmental pollution are above acceptable levels, the W2E power plant which emits more CO_2 becomes less efficient due to decrease in population and the resulting decrease in solid waste, which is the blood line of the plant.

The more solid waste generated by the increase in population, the more revenue is generated in the economy directly impacting the GDP loop and its share of investments. All of these factors, not only the income alone, but also 'how quick an income stream is realized' also influences the social-economic environments and ultimately the sustainability of the society.

Thus, the causal relationships developed in the model, which were based on the available knowledge about the real system, provided a sort of 'empirical' structural validation (Zebda, 2002). The adopted sub-models of the existing models of the domain served as a 'theoretical' structural validation (Forrester and Senge, 1980) for the municipal utility complex model.

6.3 Dimensional Consistency

Dimensional consistency test requires that each mathematical equation in the model be tested to see if the measurement units of all the variables and constants involved are dimensionally consistent. We checked and confirmed dimensional consistency of each of the mathematical equations in this model. For instance, the following equation represents one of the equations:

$$\text{Electricity Sales } \left(\frac{\$}{\text{Year}}\right) =$$

$$\frac{\text{Total Amount incinerated}}{(\text{Time} - \text{Initial Time} + 1)} \left(\frac{\text{Ton}}{\text{Year}}\right) \text{ x W2E Plant} \left(\frac{\text{MWh}}{\text{Ton}}\right) \text{ x Sale Price } \left(\frac{\$}{\text{MWh}}\right)$$

This equation describes that the electricity sales is dependent on three components (1) the total amount incinerated per year, (2) the W2E plant generation capacity of Mega Watts hour per tonnage of garbage incinerated, (3) and the sale price per Mega Watts hour produced. This equation is dimensionally consistent as we do the dimensional analysis of the equation above, we have

$$\left(\frac{\$}{\text{Year}}\right) = \left(\frac{\text{Ton}}{\text{Year}}\right) \text{x} \left(\frac{\text{MWh}}{\text{Ton}}\right) \text{x} \left(\frac{\$}{\text{MWh}}\right) = \left(\frac{\$}{\text{Year}}\right)$$

Thus, not only the value of electricity sales is based on the existing knowledge of the real system but also the equation is dimensionally consistent.

6.4 Parameter Verification

The values assigned to the parameters are sourced from the existing knowledge and numerical data of Pasco County. For illustration purpose, Table 3 lists some of the parameters and their values.

Table 6-1 Parameters for simulating a municipal utility complex model

Parameter	Value
% of Ash	0.25
% of business	0.75
% of waste combusted	0.117
avg. amount of solid waste generated per person/day	4.38
Avg. Decay Rate	0.167
birth rate	0.012504
capita/house	2.5
consump rate	0.45
cost to build a school	3.00E+06
CPI	0.035
death rate	0.0145
exit rate	0.05
govmt. spending	1.00E+08
invest. rate in Ed	0.19
labor fraction	0.38
net migration rate	0.033549
rate	0.18
rated capacity	1050*365
schooled time	2
time for waste collection	1/365
time goal to fill gap	0.333333
time to be employed	0.8
time to build	0.75
time to exit	2
unemployment rate	0.12

6.5 Extreme Condition Test

In this test, extreme values are assigned to selected parameters and then the model-generated behavior is compared to the reference (or anticipated) behavior of the real system, under the same extreme condition. As extreme condition, we set the CO_2 emissions resulting from electricity production to 10 tons per KWh instead of the average 0.91 kg/KWh. As shown on Figure 6-1, after a little initial rise follows path, similar to that of the current model, the environmental pollution starts to show its impact on population, and the population starts to decline accordingly. The initial rise may be due to time delay for the CO_2 emissions to reach lethal level. Eventually, when the CO_2 emissions rate is much higher than the absorption rate, death rate is much higher than births or net migration rate and the population trajectory descends. We observe that under this extreme condition, the model exhibits a behavior that is in line with the anticipated behavior of the real system.

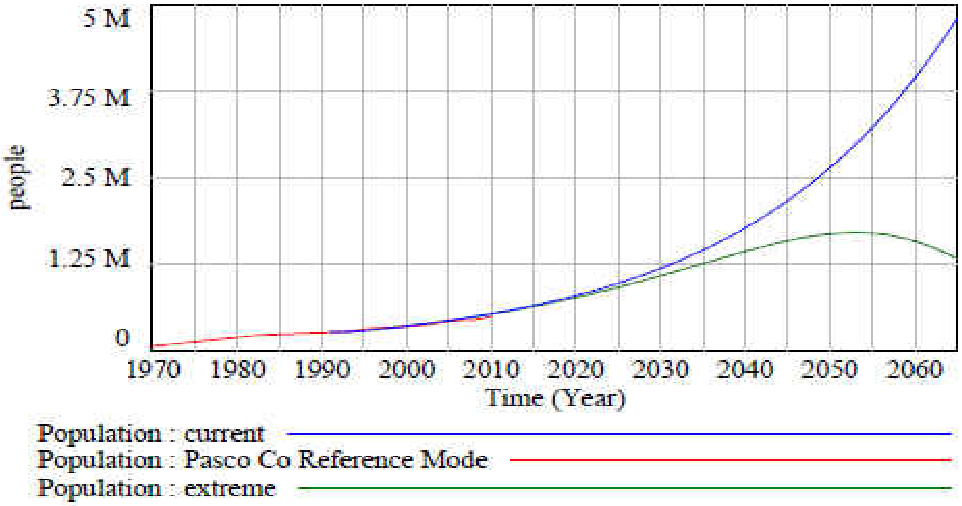


Figure 6-1. Population – impact of an extreme CO_2 emissions of10 tons/KWh

As another extreme condition, we set “time to build” to a large number (like 100 years), which in reality means ‘‘no construction’’ in the total houses in the market. The resulting behavior of the model is presented in Figure 6-2. The population exhibits a steady decline pattern, eventually approaching a flat level. The reason is obvious: the property loop responsible for the addition of new houses breaks out. Even under the influence of better economic conditions (increased GDP), there is always a need for additional houses to accommodate the increase in population. But longer time to build new houses influences and limits the population to the number of houses available, which continues to decline based on an average decline rate, makes the eventual total depletion of the population stock to follow a much flatter trajectory.

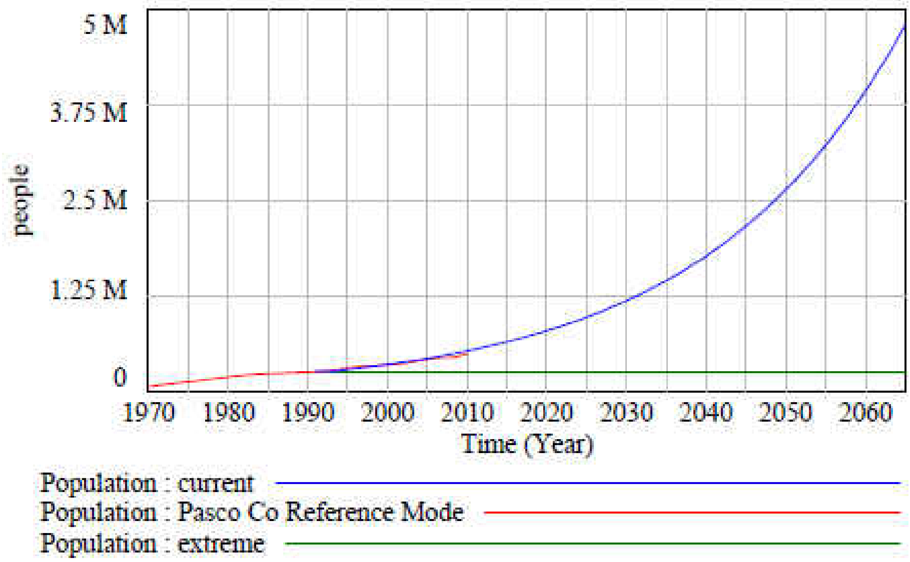


Figure 6-2. Population – impact of an extreme 100 year time to build

Again, we observe that under this extreme condition, the model exhibits a behavior that is in line with the anticipated behavior of the real system. Therefore, we conclude that this model passes the extreme condition test and its validity is enhanced.

CHAPTER 7
MODEL VALIDATION

7.1 Historical Fit

The most logical quantitative test of a predictive model is its ability to make predictions. When a model is calibrated with best-fit parameter values, it is only able to make point predictions, which are unlikely to follow the true behavior of the system exactly. The chances that complex model predictions will agree exactly with the experimental results is very remote. There are always errors in experimental measurements and there is always uncertainty associated with the model parameters. The standard method in statistics to estimate the overall uncertainty is to perform the experiment, independently, multiple times. We can then evaluate some measure of whether the model predictions and the experimental observations agree within the scatter of the data, and test whether the model predictions are statistically consistent with the experimental observations. The method of propagating the uncertainty in the model input parameters is appropriate. There is an added benefit to using the propagation of uncertainty method. The standard statistical method of performing repeated experiments to generate enough samples to characterize the uncertainty helps define the level of uncertainty, but does not require that we fully understand the sources of this uncertainty. In this validation we will compare the model-generated behavior to the observed behavior of the real system. A number of statistical tests have been suggested in the validation literature for comparing the output data from a system dynamics based simulation model with corresponding data from real world system. Here we evaluate the historical fit. As indicated in Figures 7-1 through 7-4, the results of the simulation reproduce the Pasco's experience, regarding the population, employed labor, personal income and landfill capacity relatively accurately. These variables are endogenously generated in the model and sufficiently serve the purpose of our investigation. The model has been used to perform repeated validations as shown below.

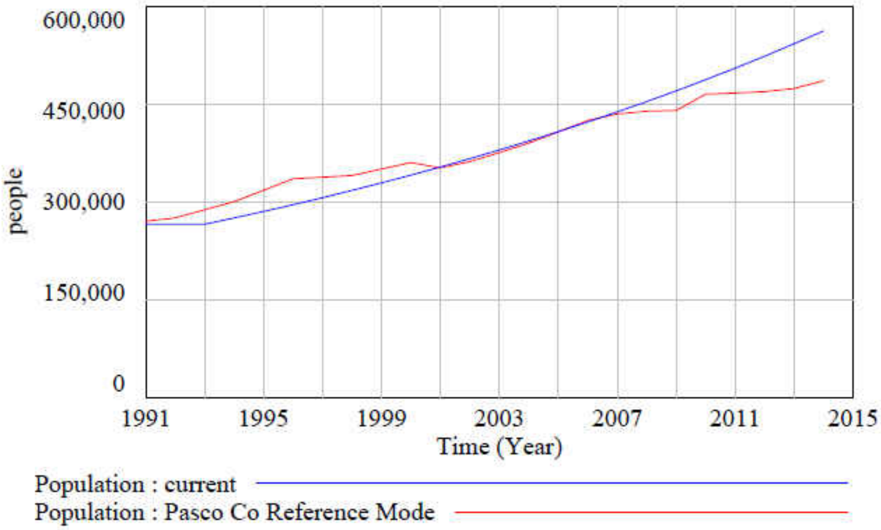


Figure 7-1. Population validation results

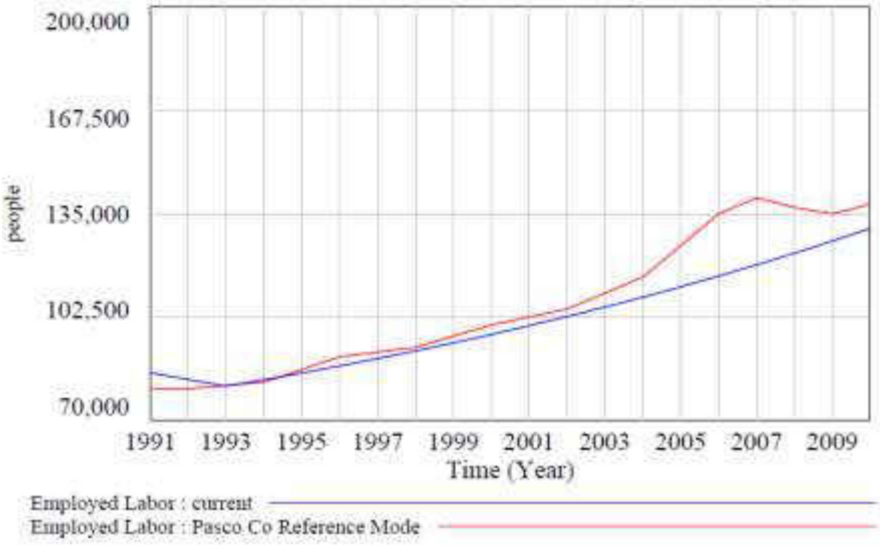


Figure 7-2. Employment validation results

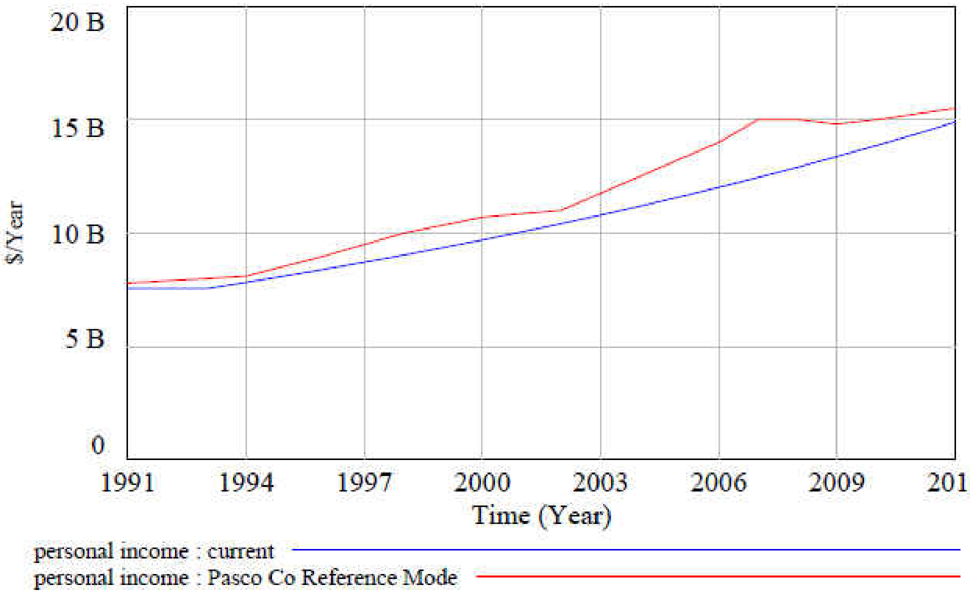


Figure 7-3. Personal Income validation results

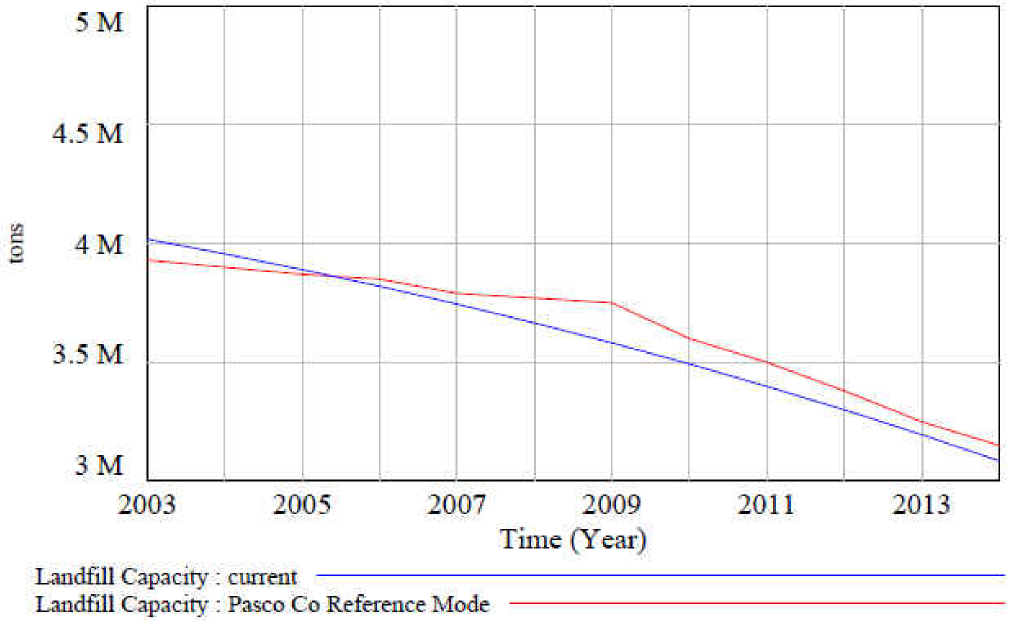


Figure 7-4. Landfill capacity validation results

7.2 Statistical Behavioral Validation

In this section we will assess how the vensim model performs in practice utilizing statistical model validation, which means how successful the model will be when applied to new or future data. A number of different statistical validation techniques have been considered with the most appropriate one being a comparison of the values predicted from the vensim model and an independent validated statistical model.

We will need to build a statistical model first for key independent variables. Since the Pasco County Utility Complex has only been operational in 1991, available data is limited as tabulated in Table 7-1. Data splitting technique will be used to split data into two parts, one part will be used to build the model and estimate its parameters (highlighted in yellow), and the other part will be used to assess its fitted predictive ability (highlighted in green). We will then run the model for 20 years, tabulate the estimated parameters and compare them to their counter parts from the vensim model.

It is worth noting that statisticians (Mendenhall and Sincich 2007) believe that even with a high r^2 value, the statistical model equation used to predict a particular value of y for the values of x falling outside the range of values of x contained in the original data may lead to errors of estimation or predictions. "*It could give a poor representation of the true model for values of x outside this region.*"

Table 7-1 Data collected for Pasco County, FL

year / variable	Population	Employed Labor	Personal Income $ (in 1,000,000)	Landfill Capacity tons
1970	75,000	20,000	$1,800	-
1972	98,000	25,000	$2,000	-
1974	125,000	30,000	$2,500	-
1976	150,000	38,000	$3,200	-
1978	175,000	40,000	$4,000	-
1980	200,000	50,000	$4,200	-
1982	225,000	55,000	$5,000	-
1984	240,000	62,000	$6,000	-
1986	245,000	76,000	$6,800	-
1988	260,000	78,000	$7,500	-
1990	265,000	80,000	$7,700	-
1992	275,000	80,000	$7,900	-
1994	300,000	82,000	$8,100	-
1996	335,000	90,000	$9,000	-
1998	340,000	93,000	$10,000	-
2000	360,000	100,000	$10,700	-
2001	351,700	-	-	-
2002	361,500	105,000	$11,000	-
2003	375,300	-	-	3,930,000
2004	389,800	115,000	$12,500	3,900,000
2005	406,900	-	-	3,870,000
2006	424,400	135,000	$14,000	3,850,000
2007	434,400	140,000	$15,000	3,790,000
2008	438,700	137,000	$15,000	3,770,000
2009	439,800	135,000	$14,800	3,750,000
2010	464,700	138,000	$15,000	3,600,000
2011	466,500	-	-	3,500,000
2012	468,600	-	$15,500	3,380,000
2013	473,600	-	-	3,250,000
2014	485,300	-	-	3,150,000

xxx data used to build the statistical model xxx data used to validate the model

7.2.1 Population Model Validation

Using statistical analysis, we develop a population regression equation as follows:

y = population, x = year count (year 1970 has an x=1)

$$y = 64{,}600 + 13{,}658\, x - 244.1\, x^2 + 3.466\, x^3$$

with $s = 10214.8$ and $r^2 = 99.4\%$

The plotted population graph along with its residuals plots are shown on Figure 7-5 and 7-6 respectively.

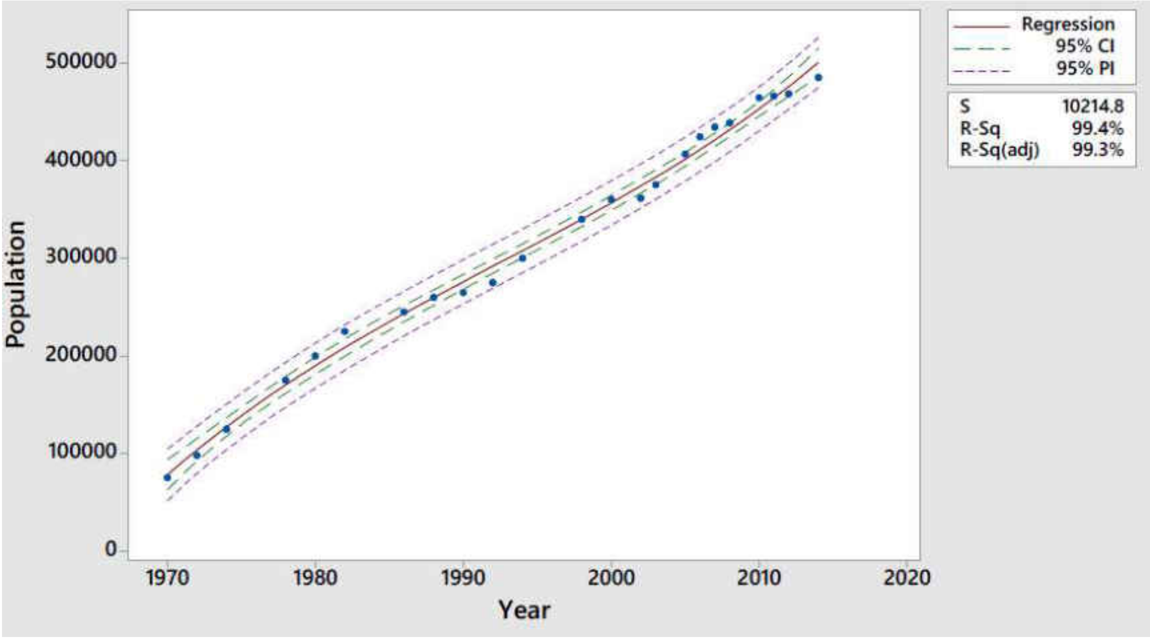


Figure 7-5. Population statistical model curve

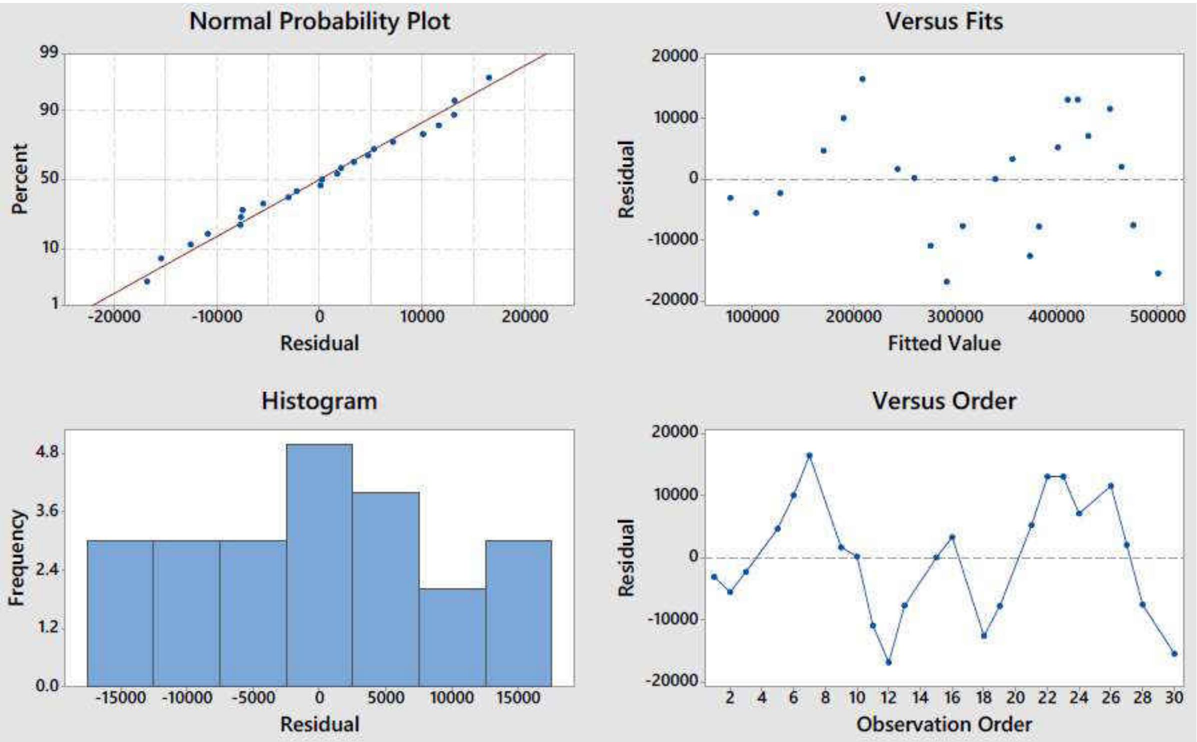


Figure 7-6. Residual plots for population statistical model

We used the other portion of the split data to validate the model, and conclude that the statistical equation represents data that falls within 95% of the confidence interval (CI=95%), and predicted data falls within also 95% prediction interval (PI=95%).

The coefficient of determination r^2 has a value of 99.4% implying that the model equation relating population to year can explain 99.4% of the variation present in the data values of population.

As shown on Figure 7-7, the statistical model predicted data closely resemble the vensim model data and thus we can state that our model has been statistically validated.

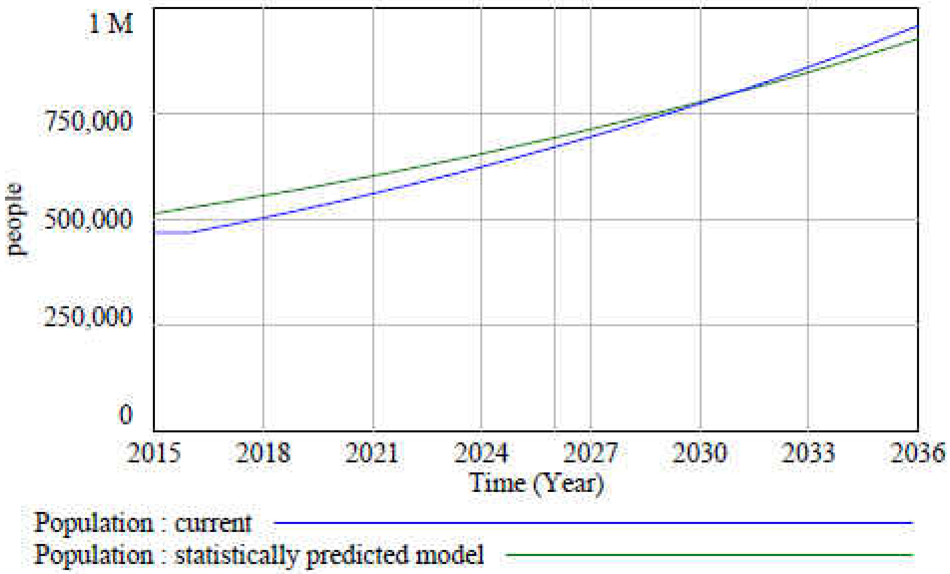


Figure 7-7. Population results of vensim model vs. statistical model

7.2.2 Employed Labor Model Validation

Using statistical analysis, we develop an employed labor regression equation as follows:

y = employed labor, x = year count (year 1970 has an x=1)

$$y = 13{,}131 + 4{,}436\, x - 108.9\, x^2 + 1.901\, x^3$$

with s = 5167.47 and $r^2 = 98.6\%$

The plotted employed labor graph along with its residuals plots are shown on Figure 7-8 and 7-9 respectively. Again, we used the other portion of the split data to validate the model, and conclude that the statistical equation represents data that falls within 95% of the confidence interval (CI=95%), and predicted data falls within also 95% prediction interval (PI=95%).

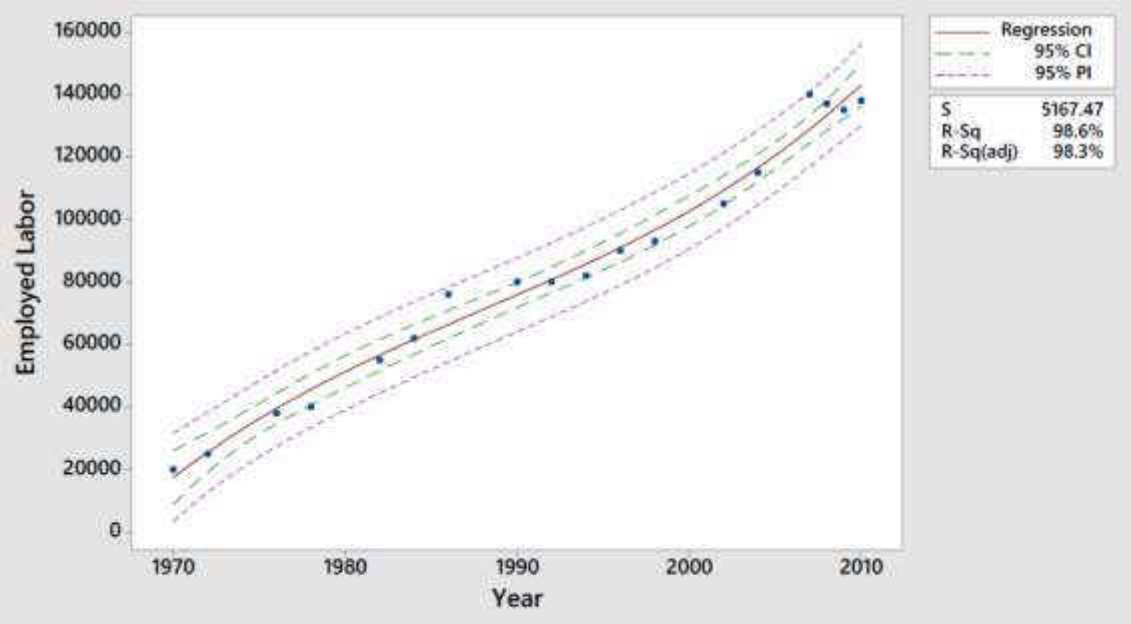


Figure 7-8. Employed labor statistical model curve

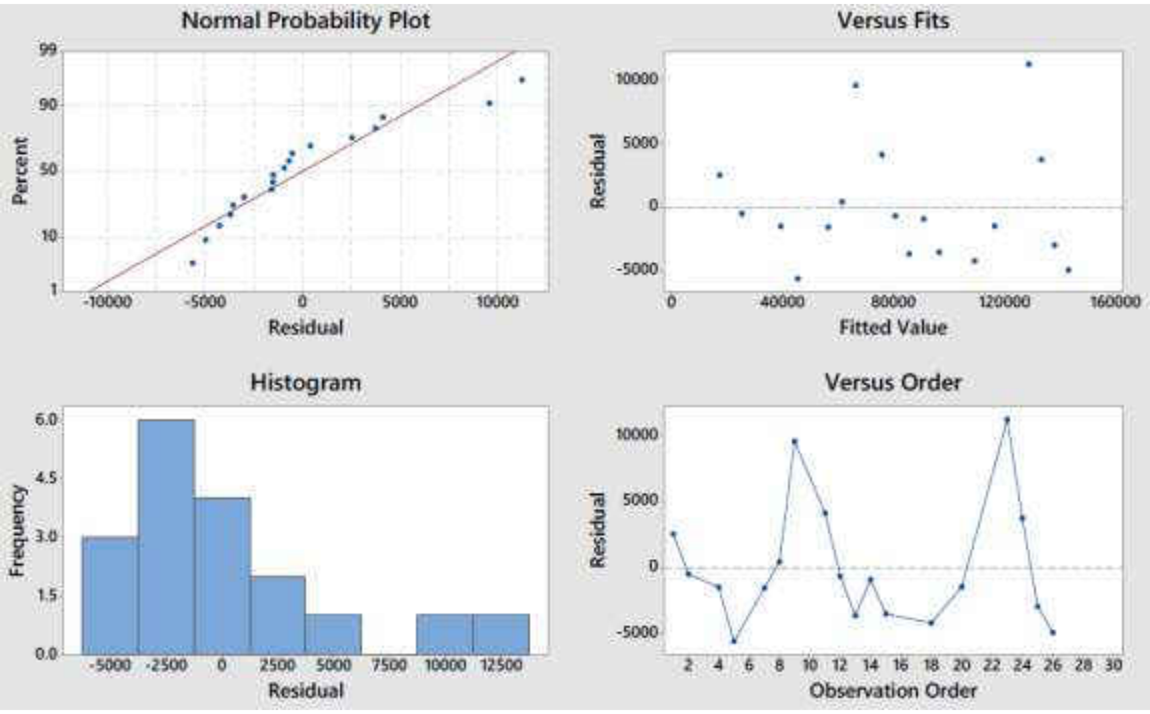


Figure 7-9. Residual plots for employed labor statistical model curve

The coefficient of determination r^2 has a value of 98.6% implying that the model equation relating employed labor to year can explain 98.6% of the variation present in the data values of employed labor.

As shown on Figure 7-10, the statistical model predicted data closely resemble the vensim model data and thus we can state that our model has been statistically validated.

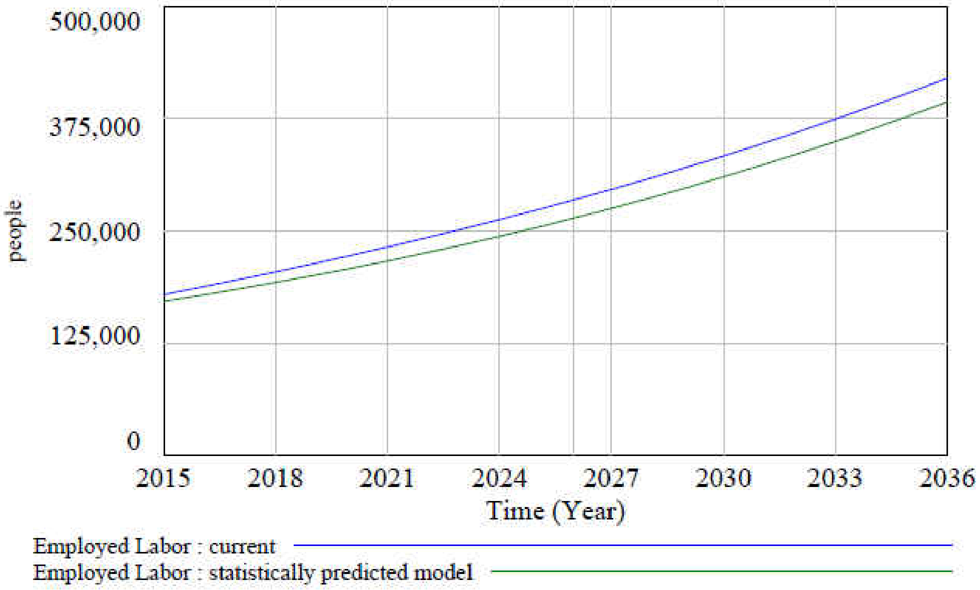


Figure 7-10. Employed labor results of vensim model vs. statistical model

7.2.3 Personal Income Model Validation

Using statistical analysis, we develop a personal income regression equation as follows:

y = personal income, x = year count (year 1970 has an x=1)

$$y = 1{,}284 + 298.8\,x - 1.006\,x^2 + 0.04845\,x^3$$

with $s = 526.339$ and $r^2 = 99.0\%$

The plotted personal income graph along with its residuals plots are shown on Figure 7-11 and 7-12 respectively. Again, we used the other portion of the split data to validate the model, and conclude that the statistical equation represents data that falls within 95% of the confidence interval (CI=95%), and predicted data falls within also 95% prediction interval (PI=95%).

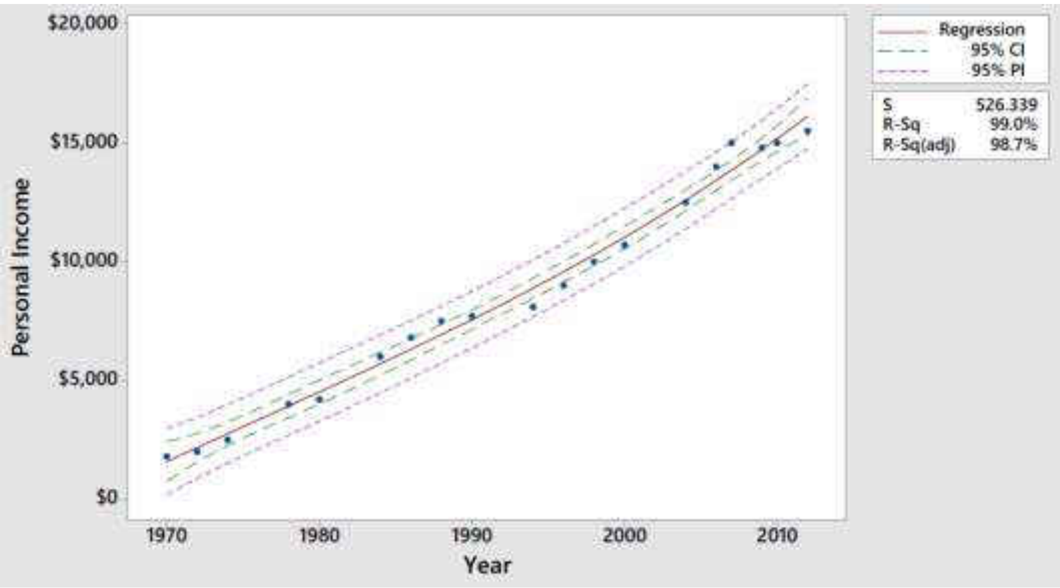


Figure 7-11. Personal income statistical model curve

The coefficient of determination r^2 has a value of 99.0% implying that the model equation relating personal income to year can explain 99.0% of the variation present in the data values of personal income.

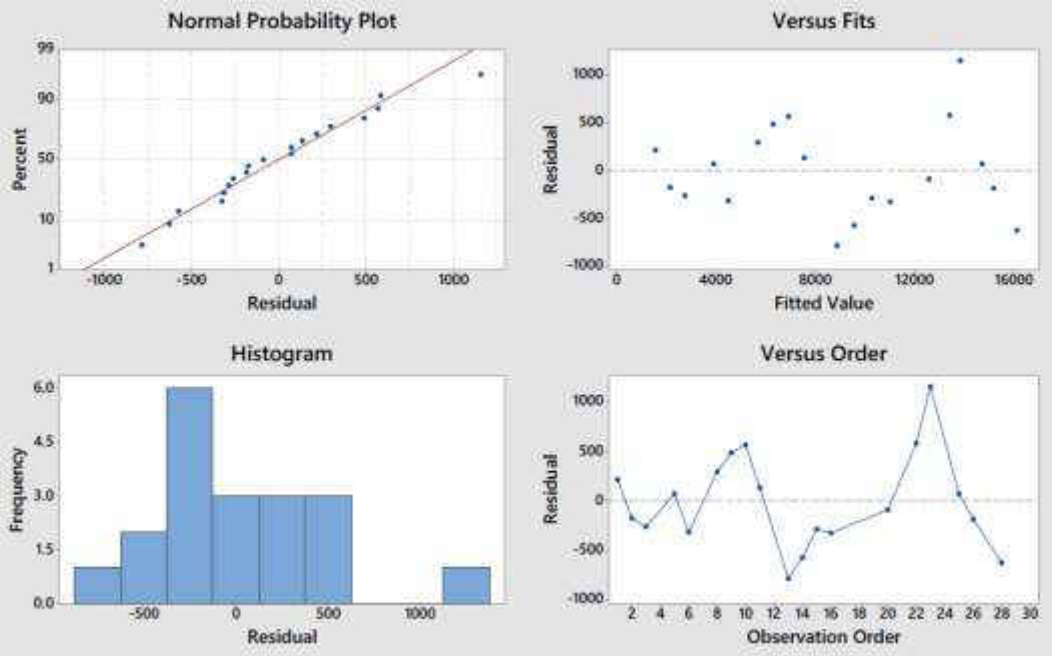


Figure 7-12. Residual plots for personal income statistical model curve

As shown on Figure 7-13, the statistical model predicted data closely resemble the vensim model data and thus we can state that our model has been statistically validated.

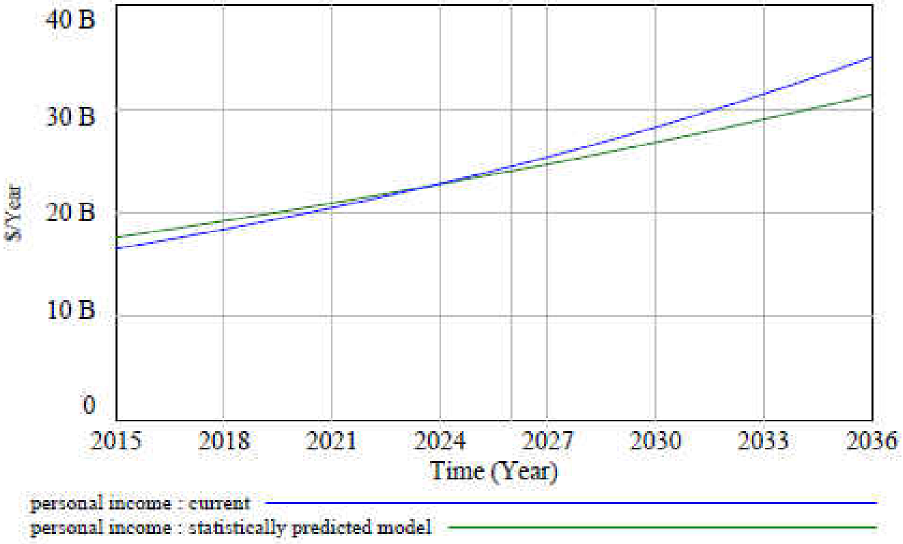


Figure 7-13. Personal income results of vensim model vs. statistical model

7.2.4 Landfill Capacity Model Validation

Using statistical analysis, we develop a landfill capacity regression equation as follows:

$$y = \text{landfill capacity},\ x = \text{year count (year 2003 has an } x=1)$$

$$y = 3{,}925{,}206 - 806\,x - 3{,}541\,x^2 - 159.3\,x^3$$

$$\text{with } s = 33{,}224.6 \text{ and } r^2 = 99.1\%$$

The plotted landfill capacity graph along with its residuals plots are shown on Figure 7-14 and 7-15 respectively. Again, we used the other portion of the split data to validate the model, and conclude that the statistical equation represents data that falls within 95% of the confidence interval (CI=95%), and predicted data falls within also 95% prediction interval (PI=95%).

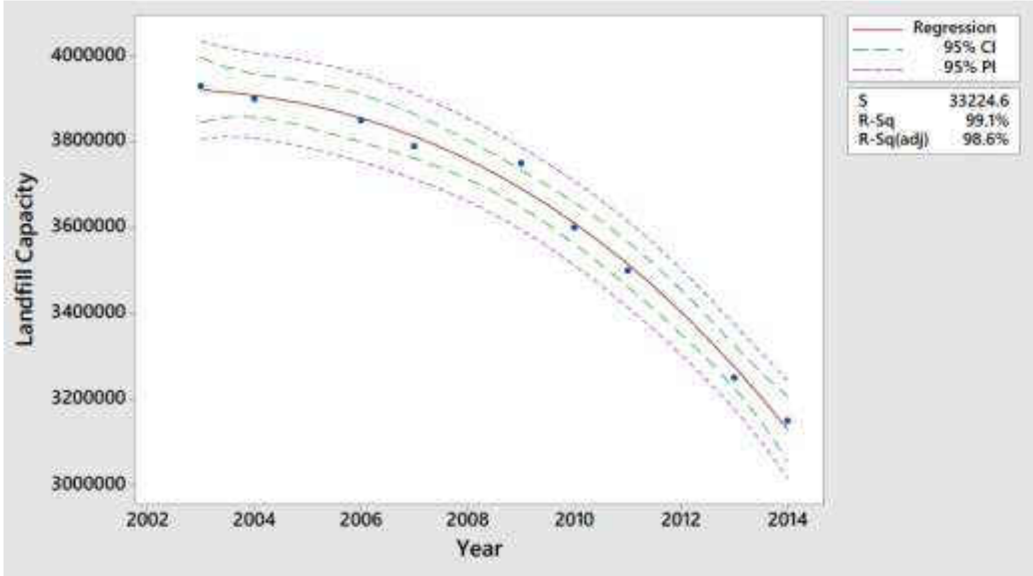


Figure 7-14. Landfill capacity statistical model curve

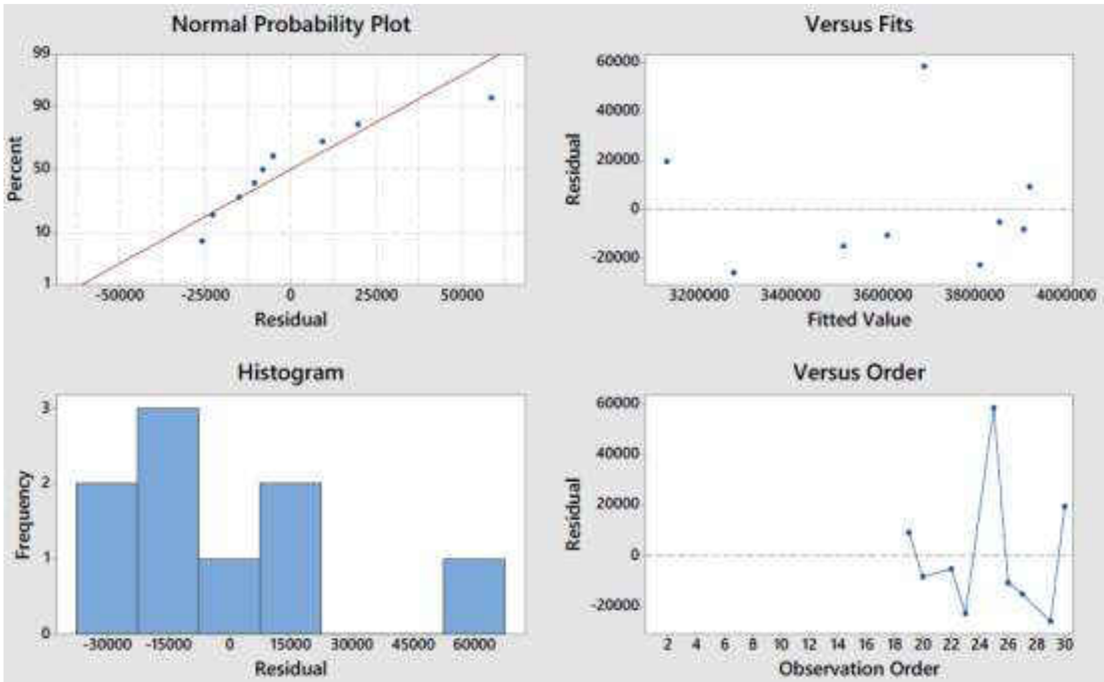


Figure 7-15. Residual plots for landfill capacity statistical model curve

As shown on Figure 7-16, the statistical model predicted data closely resemble the vensim model data and thus we can state that our model has been statistically validated.

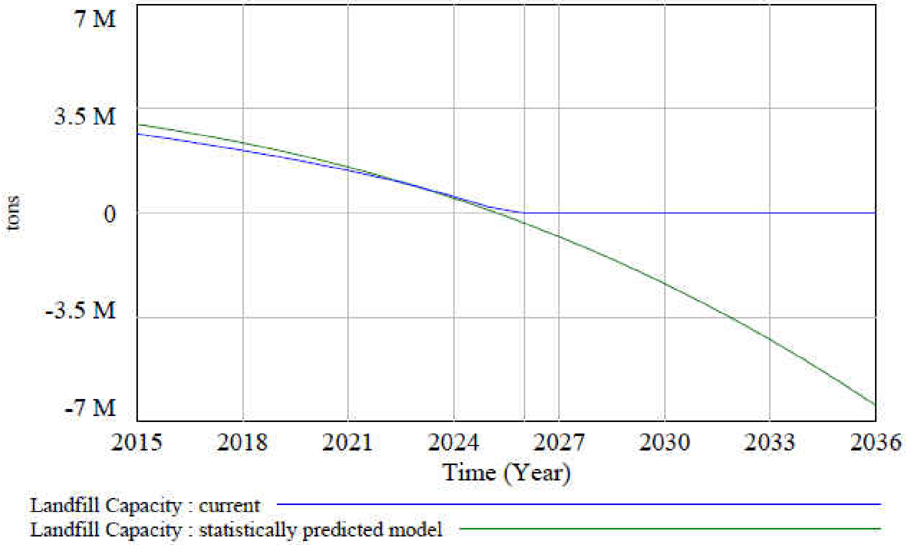


Figure 7-16. Landfill capacity results of vensim model vs. statistical model

7.3 Model Correlation Analysis

In order to identify the most important variables in the proposed vensim model, we performed a stepwise regression analysis to evaluate its performance in terms of the sustainable impact of the environmental and socio-economic systems of the municipal utility complex (MUC) on the population. Table 7-2 below presents data simulated in the model from 2015 to 2065 where,

Y = Population

X1 = Total number of houses

X2 = Employed labor

X3 = Electricity sales ($/year)

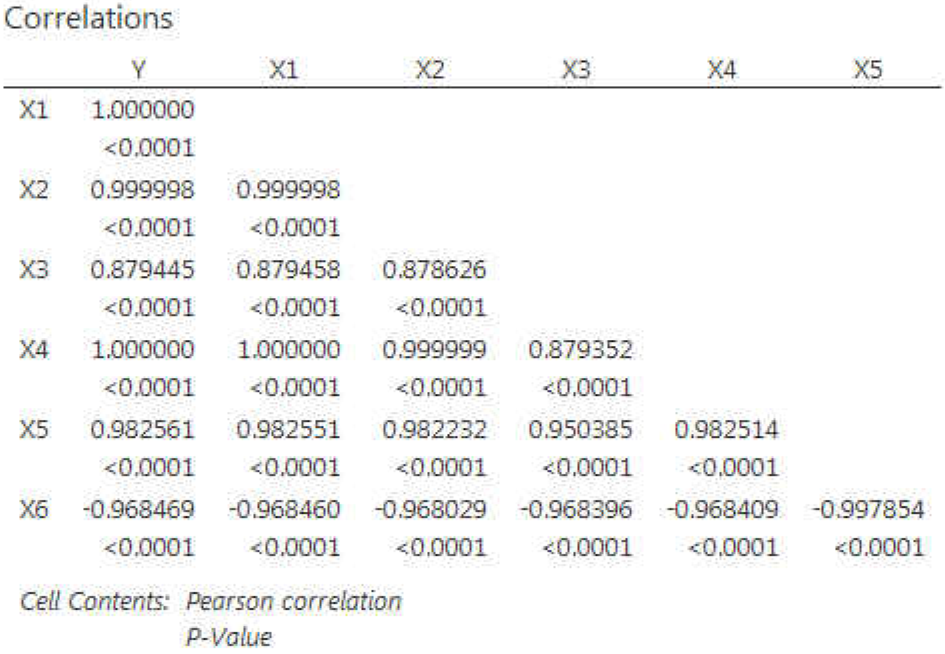
X4 = Total garbage fees ($/year)

X5 = Amount of CO_2 (GtC)

X6 = Land fill capacity (tons)

Examining the correlations between the variables, we find that Y, X1, X2, X3, X4, X5 and X6 have high correlation with each other, indicative of the extreme likelihood of multi-collinearity in this multiple regression analysis.

Table 7-2 Correlations analysis



Correlations

	Y	X1	X2	X3	X4	X5
X1	1.000000					
	<0.0001					
X2	0.999998	0.999998				
	<0.0001	<0.0001				
X3	0.879445	0.879458	0.878626			
	<0.0001	<0.0001	<0.0001			
X4	1.000000	1.000000	0.999999	0.879352		
	<0.0001	<0.0001	<0.0001	<0.0001		
X5	0.982561	0.982551	0.982232	0.950385	0.982514	
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
X6	-0.968469	-0.968460	-0.968029	-0.968396	-0.968409	-0.997854
	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Cell Contents: Pearson correlation
P-Value

Running the regression model using variables, and calculating the variance inflation factor (VIF) for each, we get the following regression equation:

Y = - 701475 + 7.938 X1 + 27.89 X2 + 0.08092 X3 - 0.12944 X4 + 504.5 X5 + 0.01799 X6

X5 (amount of CO2 (GtC)) has the highest VIF, so we will remove it and run the model again

The 2nd regression equation

Y = - 202618 + 9.253 X1 + 42.32 X2 + 0.06983 X3 - 0.18196 X4 - 0.020377 X6

X2 (employed labor) has the highest VIF, so we will remove it and run the model again

The 3rd regression equation

$Y = 28571 + 1.255\ X1 - 0.02726\ X3 + 0.00246\ X4 - 0.003622\ X6$

With VIF of all variables being < 5, this is a reasonable regression model. After removal of multi-collinearity variables (namely X2 and X5), we find that X1, X3, X4 and X6 are significant variables for this model and all other independent variables are insignificant.

$\beta 0 = 28571$ This is simply the estimate of the y-intercept and does not have any practical interpretation

$\beta 1 = 1.255$ For each unit increase in total number of houses, we estimate the population will increase by 1.255 units, holding X3 (electricity sales), X4 (total garbage fees) and X6 (landfill capacity) at 0

$\beta 2 = -0.027$ For each unit increase in X3 (electricity sales), we estimate the population will decrease by 0.027 units, holding X1 (total number of houses), X4 (total garbage fees) and X6 (landfill capacity) at 0 β3 = 0.0024 For each unit increase in X4 (total garbage fees), we estimate the population will increase by 0.0024 units, holding X1 (total number of houses), X3 (electricity sales) and X6 (landfill capacity) at 0

β4 = -0.0036 For each unit increase in X6 (landfill capacity), we estimate the population will decrease by 0.0036 units, holding X1 (total number of houses), X3 (electricity sales) and X4 (total garbage fees) at 0

Since the model is not intended for forecasting but rather for policy analysis, the exclusion or inclusion of X2 (employed labor) and X5 (amount of CO_2) is of little concern, as it will not affect the relative efficacy of policies. As a result, it is fair to conclude that the model used for policy analysis rather than forecasting purposes, accurately replicates the actual data.

CHAPTER 8
POLICY ANALYSIS

8.1 1st scenario “Lower CO_2 Emissions” Policy

The U.S. Environmental Protection Agency's proposal for existing power facilities, a major part of President Obama's climate initiative, will set a national target of lowering these CO_2 emissions — from 2005 levels — by 25 percent by 2020 and 30 percent by 2030. The rule will not be finalized until next year, at which time Florida will have only until June 2016 to develop and submit plans for cutting emissions about 38 percent.

At a time when electricity consumption in the United States is projected to grow, these new rules will require Counties having power plants to significantly reduce their carbon emissions, leaving these facilities with the difficult choice to upgrade, shut down or invest in a new or another waste to energy plants (W2E). Given that Florida generates about one quarter of its electricity from coal, both options mean higher electricity prices for Florida consumers.

Recently in Pasco County, community leaders gathered for a tour of the Municipal Utility Complex which houses the first waste-to-energy plant built back in 1989. Decision makers are contemplating building a new facility by 2020 as it plays a larger role in the county's energy mix, especially with the recent rules proposed by the U.S. Environmental Protection Agency regarding carbon emissions for new and existing power plants. A proposed new plant will be designed to process more than 0.3 million tons of solid waste per year and generate enough renewable energy to power more than 15,000 homes. They also plan to partially finance the project by increasing the garbage fees by 10% by 2020. Table 5 shows quick facts about the County as listed by the United States Census Bureau.

The model will be utilized to analyze the impact of this policy on the population growth, employed labor, landfill capacity, and CO_2 emissions over the next 20 years.

Table 8-1 Pasco County, Florida – Census information
(US Census Bureau 2015)

2014 County Census Information	Data
Population, 2014 estimate	1,397,710
High school graduate or higher, % persons age 25+, 2009-2013	87.5%
Bachelor's degree or higher, % persons age 25+, 2009-2013	32.4%
Housing units, 2013	669,550
Households, 2009-2013	526,007
Persons per household, 2009-2013	2.51
Building permits, 2013	5,135
Per capita money income in past 12 months (2013 dollars)	$32,858
Median household income, 2009-2013	$52,432
Employment, 2012	449,798
Employment, percent change, 2011-2012	3.1%
Land area in square miles, 2010	1,969.76
Persons per square mile, 2010	670.2

8.2 Results and Discussion - 1st scenario "Lower CO_2 Emissions" Policy

The proposed additional facility in 2020 is projected to reduce the amount of waste that will be land-filled by up to 12 percent. This could delay the need to develop and use another landfill cell in Pasco County till the year 2027 while also significantly reducing emissions of the potent greenhouse gas methane, which is created by decomposing landfill waste. The population will experience a growth rate from 25,000 per year in 2015 to over 55,000 per year in 2035. The employed labor will increase from about 175,000 in 2015 to a bit short of 375,000 by 2035. If the new facility is designed to have high combustion efficiency, it will eliminate 90 to 99 percent of acid gas, heavy metal and dioxins emissions, and the CO_2 emissions will contribute a little less than 0.0425 GtC/year in 2035.

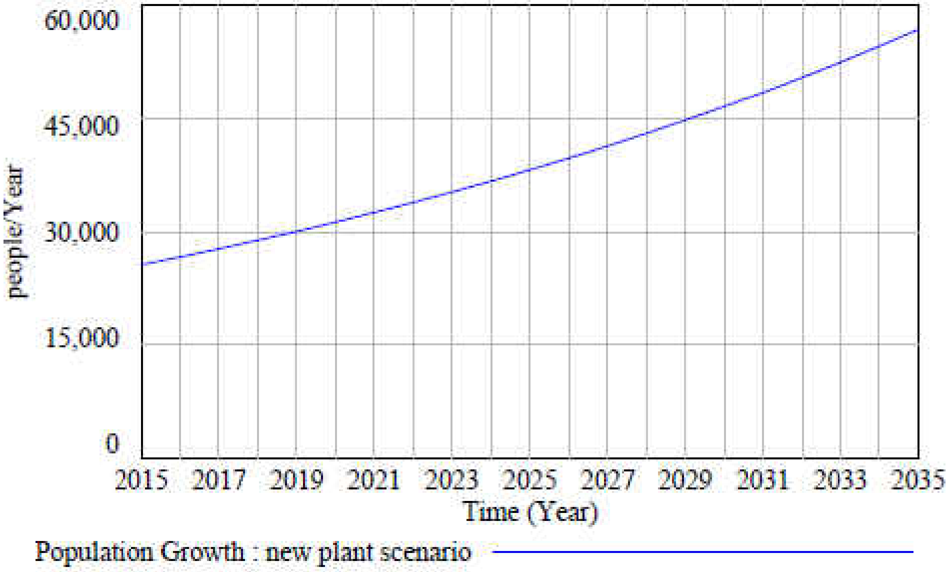


Figure 8-1. Model results - Population growth rate in the 1st scenario

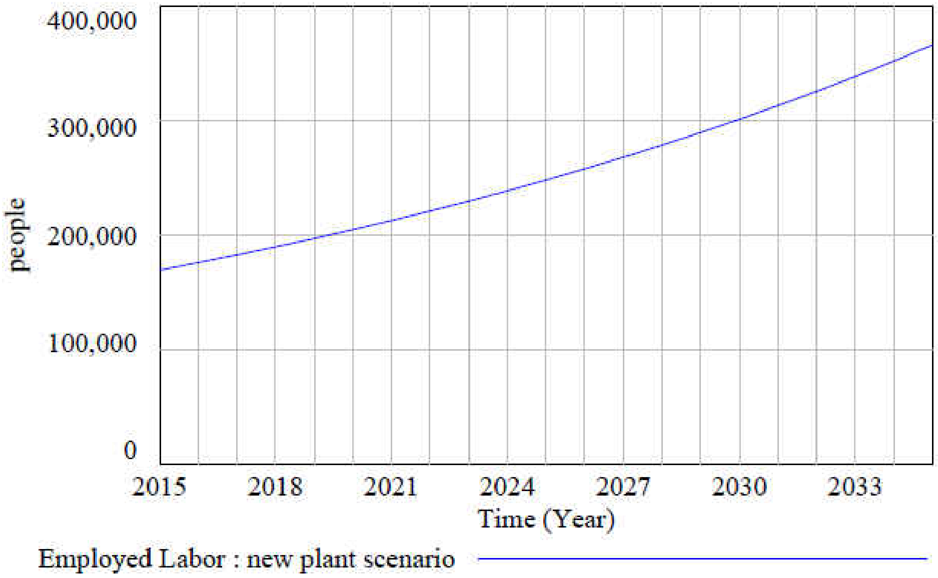


Figure 8-2. Model results - Employed labor in the 1st scenario

Constructing the new facility will decrease the amount of waste sent to the landfill as the population grows, and the amount of incinerated waste increases. Population does stabilize as soon as the capacity comes on line, although it begins to increase eventually. The relative greenhouse gas emissions are minimally affected by the processing capacity of the W2E plant, and the model run in Figure 8-4 shows the long run effect of unchanged policies.

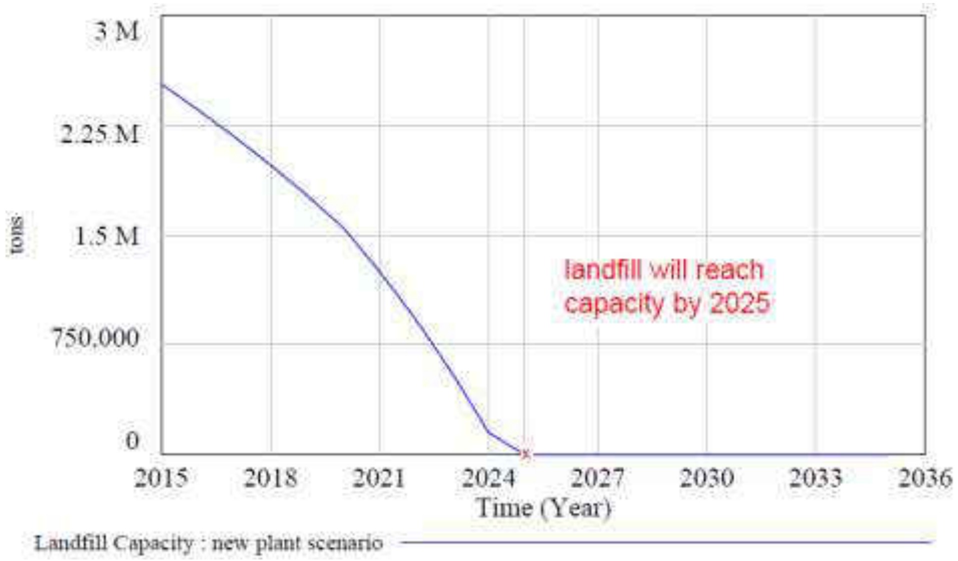


Figure 8-3. Model results – Landfill capacity in the 1st scenario

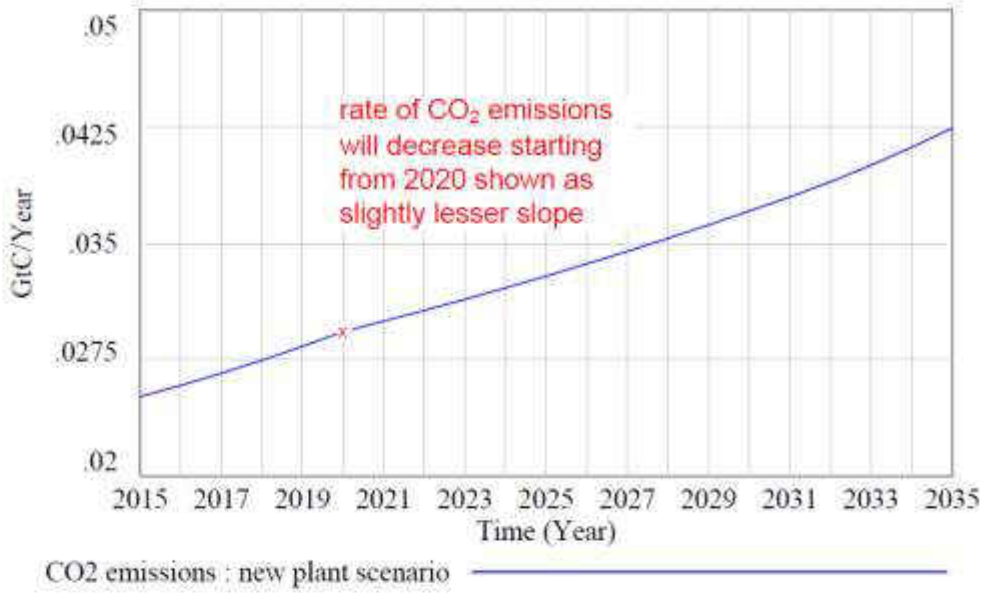


Figure 8-4. Model results – CO_2 emissions in the 1st scenario

The new W2E facility will reduce the net GHG factor as shown on Figure 8-5. The net reduction is a summation of avoided methane emissions from landfills, additional emissions from the new W2E electrical generation that offsets or displaces fossil-fuel based electrical generation, and the recovery of metals for recycling. The GHG reductions associated with these three factors more than offset WTE fossil-based CO_2 emissions from combustion of plastics and other fossil fuel-based MSW components. The U.S. EPA approximates a one ton reduction in GHG emissions for every ton of MSW combusted.

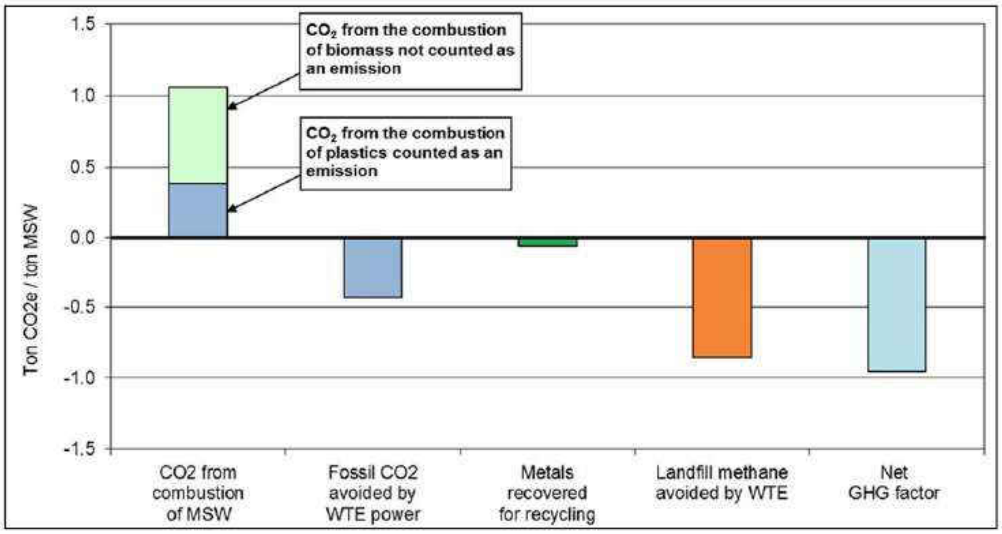


Figure 8-5. GHG & CO_2 emissions reductions as a result of new W2E in the 1st scenario (http://www.epa.gov/wastes/nonhaz/municipal/wte/airem.htm#7)

On the long term, a fixed assumption of CPI level was made of 3.5% in real terms, and the simulation shows the recognizable rapid growth of prices. An increase of 10% in household garbage fee was applied by the year 2020 and the resulted revenue and cost curves are shown in Figure 8-6 and 8-7 respectively. Note that the cost will exceed the projected revenue till the year 2035, and the county will have to finance the project with external funds till then, or increase its garbage fees by more than the proposed 10%. By the end of modeling period of 20 years, it appears that the County will reach a breakeven point, excluding any other capital improvement projects.

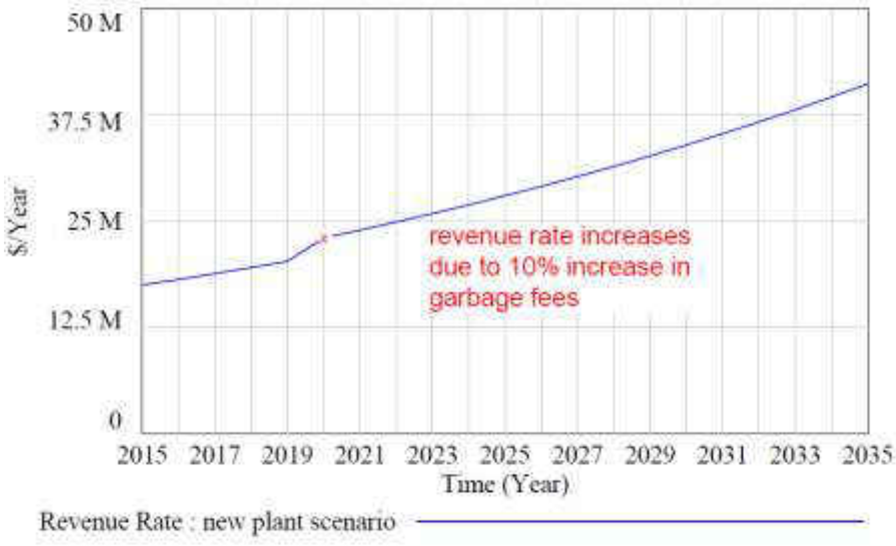


Figure 8-6. Model results – Revenue rate in the 1st scenario

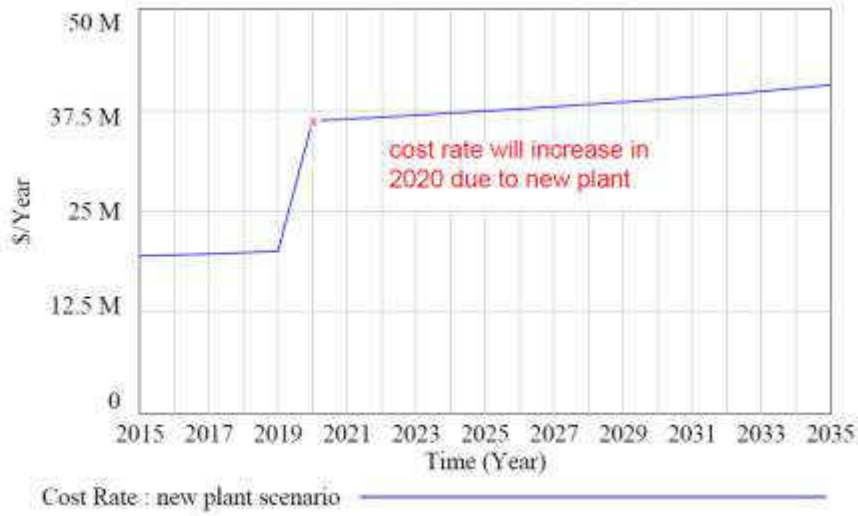


Figure 8-7. Model results – Cost rate in the 1st scenario

The scenario graphs reveal several key points about the waste system. First, without any action, waste reduction is not possible, meaning that there is no chance of lowering CO_2 emissions. In fact, taking no action will expedite erosion of the existing landfill and will not decrease the amount of greenhouse gas emission. Second, reducing waste is possible by several means, but there are significant costs and tradeoffs in environmental impact and political/social effort required. Third, reducing greenhouse gases in any significant way requires reducing the material that enters the waste system. Because the largest amount of greenhouse gas emissions in this system is generated by virgin materials in the production of goods, any policy that is intended to reduce the greenhouse gas emissions will only be effective if it reduces the amount of virgin materials used. These include increasing product durability, increasing the recycled content of products, and reducing consumption. Even small changes in these parameters can have marked effects on GHG emissions.

8.3 2nd scenario “Zero Waste” Policy

Pasco County is contemplating a “Zero Waste” policy in pursuit of sustainability, environmental achievement, and economic efficiency. The proposed policy will be introduced to the community gradually over 20 years span beginning with the year 2016. It will eliminate waste to landfills and rely on waste-to-energy facility(s) for waste that cannot be recycled. Ultimately, it will contribute to achieving a greener community, social, environmental, and economic sustainability, taking into account a “triple bottom line” approach, people, planet, and profit. In developing this policy and associated programs, the County intends to maximize diversion from landfills (through program implementation and facility development) and reduce generation of waste (through zero waste policies and education).

Zero waste is a perception change that requires rethinking what have traditionally been regarded as garbage, and treat all materials as valued resources instead of items to discard. It entails shifting consumption patterns, more carefully managing purchases, and maximizing the reuse of materials at the end of their useful life. It also takes into account the whole materials management system, from product design and the extraction of natural resources, to manufacturing and distribution, to product use and reuse, to recycling or disposal.

We will use the model to analyze the policy strictly within the municipal utility complex. For the purpose of identifying the impact of this policy on the complex, we will presume that all other programs outside the physical limits of the complex are being implemented over the 20 years introduction period. We will model the waste to landfill in such a way that it will gradually reduce until it reaches zero in year 2036, combustible waste to W2E facility will also change, and recyclables will increase as well as indicated on the municipal waste composition Table 8-2.

This policy will obviously have financial impacts on system fees as well (hauling, tipping, and franchise), customer garbage rates, recycle expenses, County's revenue streams, and investment in additional infrastructure. All these impacts are discussed in details in the results and discussion section.

Table 8-2 Pasco County, Florida – Municipal Solid Waste information

(Florida Department of Environmental Protection FL-DEP 2013)

1 Population[1] 473,566

2 MSW Management (tons)[2]

A.	Landfilled	189,467
B.	Combusted	236,020
C.	Recycled	238,093
D.	Stockpiled	0
E.	Total	663,580

E. Total Pounds per Capita Per Day 7.68

3 MSW Collected & Recycled

		Collected (tons)	Recycled (%)
A.	**Minimum 4 of 8**[3]		
	Newspaper	16,856	0%
	Glass	9,669	0%
	Aluminum Cans	3,145	0%
	Plastic Bottles	14,638	0%
	Steel Cans	5,209	0%
	Cardboard	52,440	0%
	Office Paper	13,900	0%
	Yard Trash	49,315	0%
B.	**Other Recyclables**		
	Other Plastics	45,040	0%
	Ferrous Metals	50,135	0%
	White Goods	8,491	0%
	Non-ferrous Metals	14,052	0%
	Other Paper	64,600	0%
	Textiles	12,049	0%
	C&D Debris	229,107	0%
	Food	36,839	0%
	Miscellaneous	35,882	0%
	Tires	2,213	0%
	Processed Fuel	N/A	0%

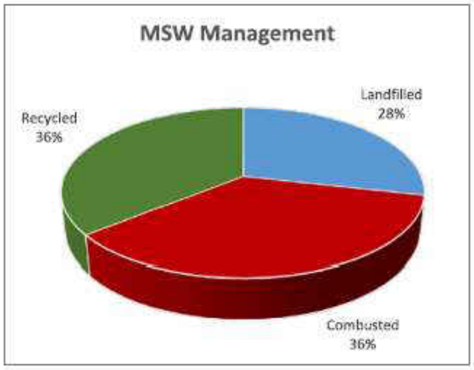
C.	**Traditional Recycling Rate (%)**	
	1) Unadjusted	36%
	2) Adjusted	36%

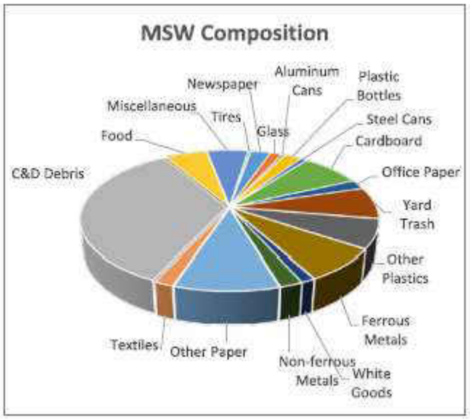
		Mwh	Recycling Credit (%)
D.	**Renewable Energy Recycling Credits**		
	1) Waste-to-Energy	207,408	31.26%
	2) Landfill Gas	0	0.00%
	3) Renewable Energy (other than WTE)	0	0.00%

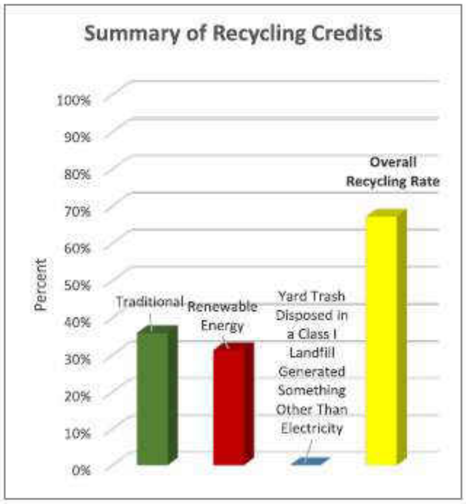
		Mwh	Recycling Credit (%)
E.	**Yard Trash Disposed in a Landfill Beneficially Using Landfill Gas (for (something other than electricity)**	0	0.0000%

F.	**Overall Recycling Rate (%)**	
	1) Unadjusted	67%
	2) Adjusted	67%

		Units	Percent
G.	**Participation in Recycling**		
	1) Single Family Curbside	186,691	19%
	2) Multi-Family Curbside	0	0%
	3) Commercial		
	a) Scheduled Collection	0	0%
	b) On Call Collection	0	0%







8.4 Results and Discussion - 2nd scenario

In modeling the zero waste scenario, materials that are customarily landfilled will be recycled, composted or combusted. The model assumes that the County will capture those materials through expanding existing programs and developing new collection programs. It also assumes that all of the existing materials will exist in the same proportions in future years. In reality, some materials will change, as new products are developed and older products decrease in market share. In addition, some materials will disappear from the waste stream through new source reduction efforts, such as reduction of plastic bag use as more residents use canvas bags, or reduction of yard trimmings as more residents start backyard composting or xeriscaping. The model attempts to estimate the maximum amount of materials that will need to be processed by assuming that no source reduction will occur. This is done in order to ensure that the County has sufficient processing capacity in case the zero waste programs were not as efficient as anticipated. In developing the model we used waste composition data for each waste sector shown on Table 6 to create a profile of recoverable and non-recoverable waste types.

Figure 8-8 shows results for the % of waste discarded gradually reducing from its current value of 53.8% to 0% over a 20 years period starting from the year 2016 and ending on 2036. Likewise, the waste discarded rate will decrease over the same period to achieve the intended zero waste policy.

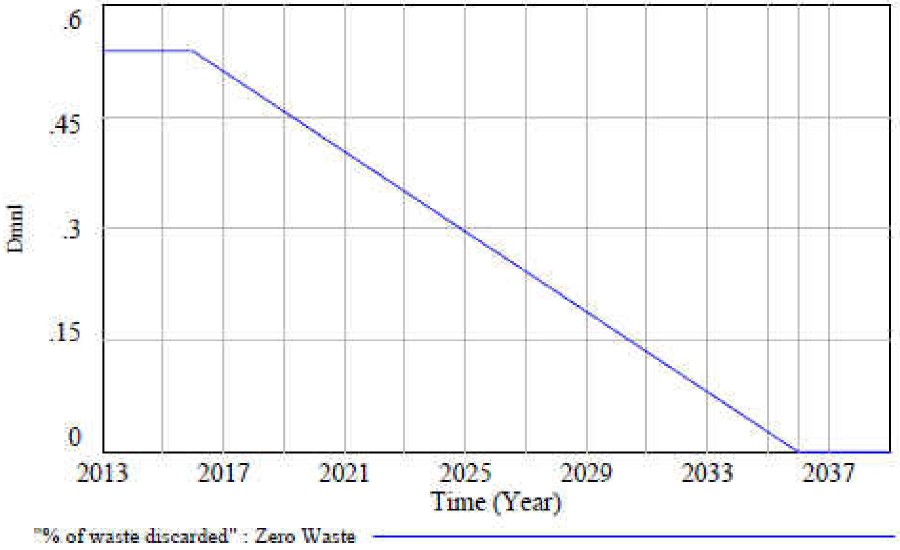
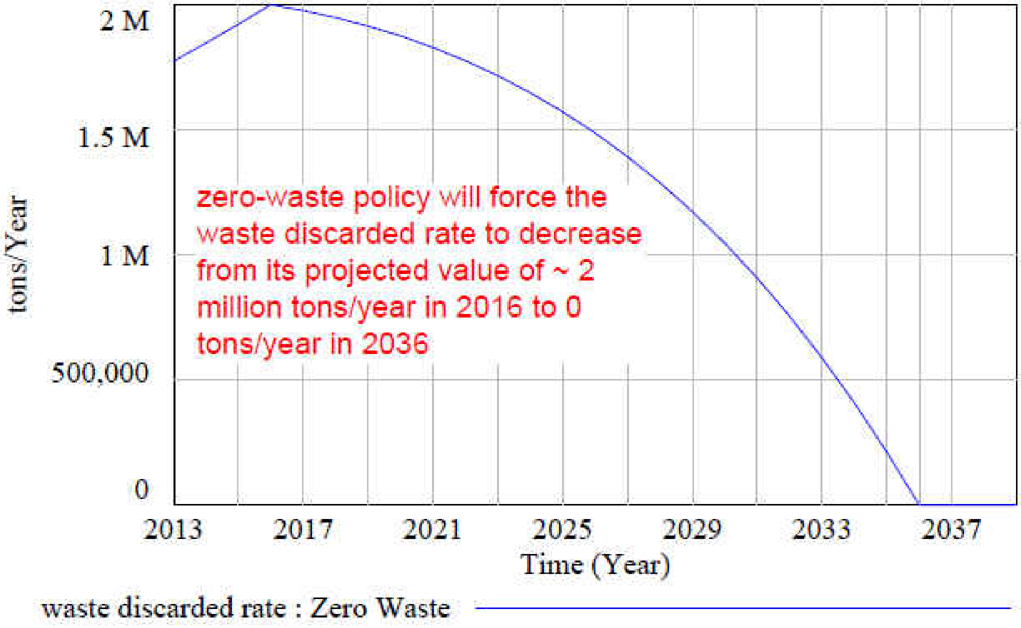


Figure 8-8. Model results – Zero Waste - % waste discarded



zero-waste policy will force the waste discarded rate to decrease from its projected value of ~ 2 million tons/year in 2016 to 0 tons/year in 2036

Figure 8-9. Model results – Zero Waste – waste discarded rate

Because the waste discarded to landfill will reduce, the % of waste recycled will gradually increase from its current value of 34.5% to a projected 64% over a 20 years period, and the % of waste combusted will also gradually increase from its current value of 11.7% to 36%.

The projection is based on the FDEP data for similar size community as shown on Table 8-2, Figure 8-10 and 8-11 depicts the results.

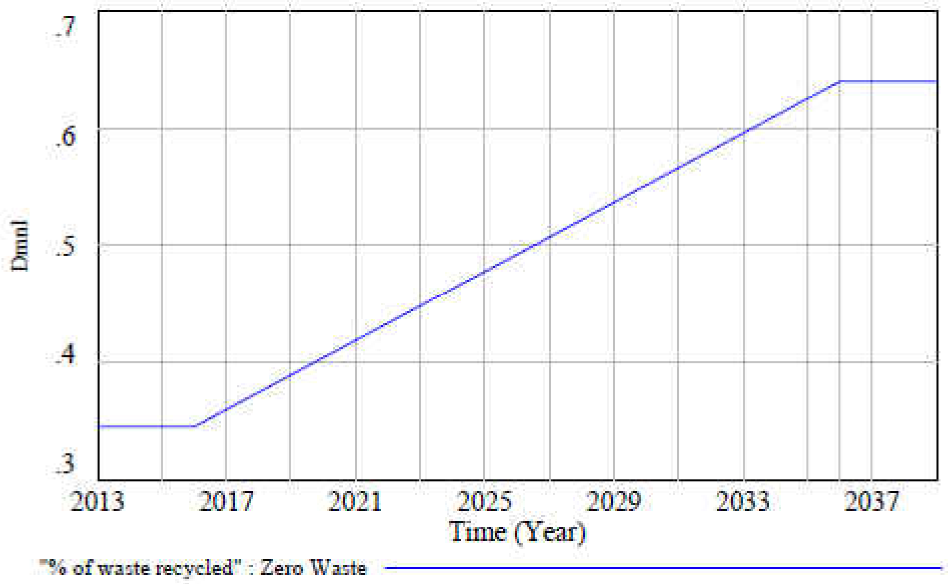


Figure 8-10. Model results – Zero Waste - % waste recycled

Figure 8-11. Model results – Zero Waste - waste recycled rate

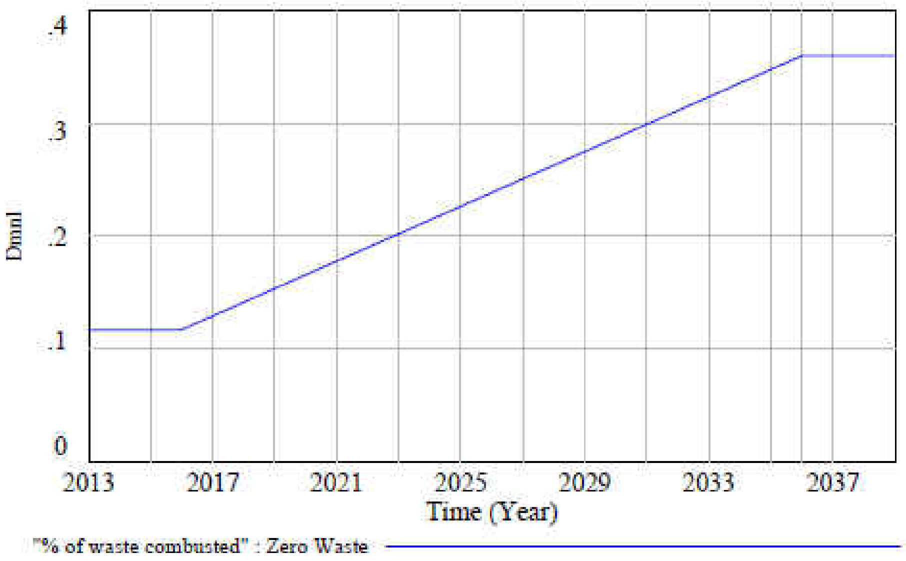


Figure 8-12. Model results – Zero Waste - % waste combusted

Figure 8-13. Model results – Zero Waste - incineration rate

Interesting observation that's worth noting, as the combusted waste increase, the current W2E plant will have to be upgraded eight (8) times by the year 2036 resulting in an increase in the rate of ash as a byproduct of the incineration process. The model automatically upgrades the plant capacity and subsequent costs once the maximum design capacity is reached as shown in Figure 8-14. The ash is currently used as a cover layer over the discarded waste in the landfill, and will continue to be used as such as shown on Figure 8-16. The zero waste policy will cause each cell within the landfill to gradually fill with ash and its respective capacity decreases until it reaches zero, and the next cell will be used as shown on Figure 8-15. The waste incineration will continue to yield ash and both will continue to increase due to population growth. Note that the model predicts a continuous climb in the rate of ash due to upsizing the W2E plant to accommodate the increase in waste. To manage the additional ash, the County is studying the possibility of using ash as an admixture to sand in the pavement's base material, and analyzing the potential impact to the concrete and asphalt pavement yield strength.

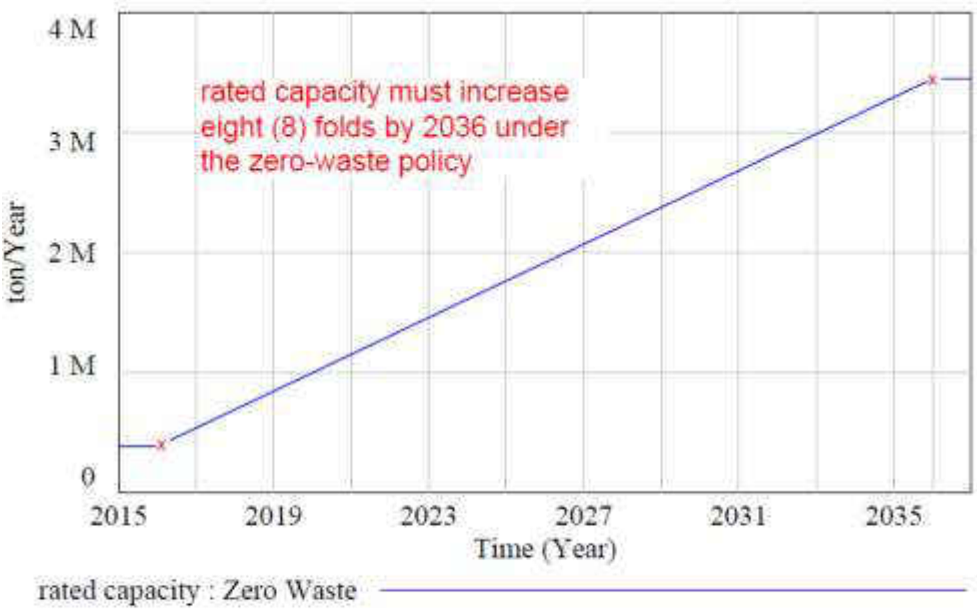


Figure 8-14. Model results – Zero Waste – plant rated capacity

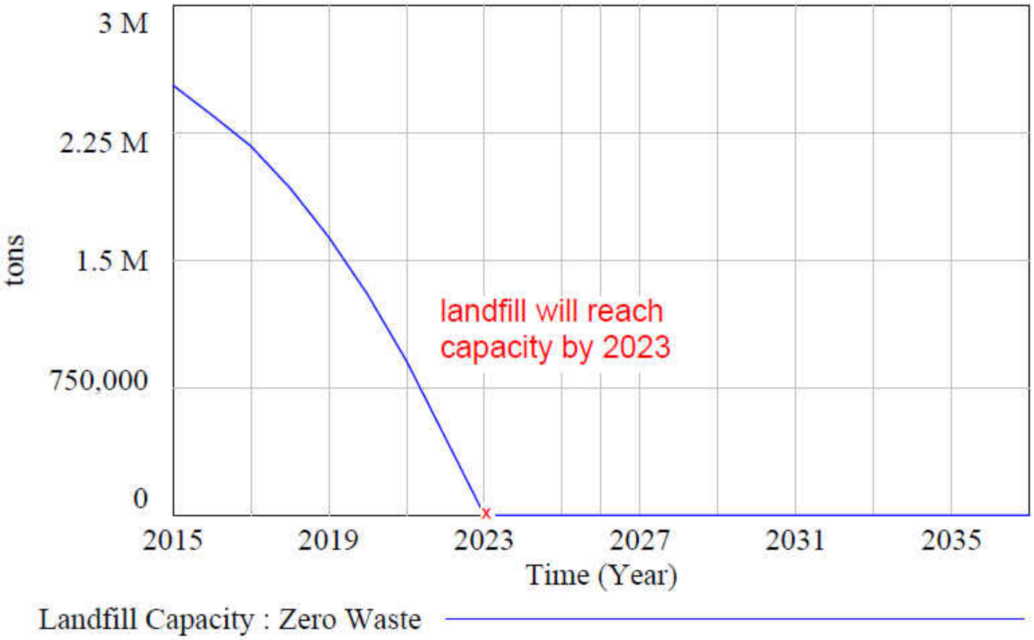


Figure 8-15. Model results – Zero Waste – landfill capacity

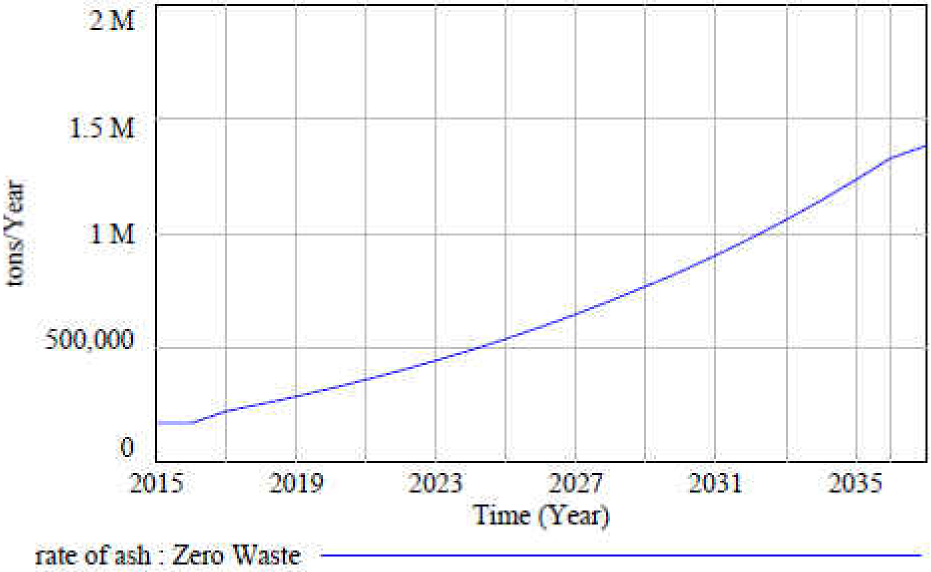


Figure 8-16. Model results – Zero Waste – rate of ash

From a financial standpoint, finances and funding of recycling programs have historically been made from household garbage fees. The County's fee for the residential collection programs is $5.70 and is used to pay for garbage, recycling, and yard trimmings collection. Commercial haulers pay a franchise fee based on the volume of solid waste collected for disposal. Assuming that no source reduction will occur (safe assumption for modeling purposes), over the mid to long-range, as the County's zero waste programs become more successful in reducing the need for landfill disposal, the County's municipal utility complex costs and revenues structure will have to change, and there will be a need to identify alternative means of funding such as source reduction and recycling fee. For the purpose of this model, we assumed that the County's intent is to even out the total cost and total revenues of the MUC through a recycling fee structure that has a 10% gradual increase over the 20 years plan from $0.60 at 2016 to $3.60 in 2036 (Figure 8-17), after that, the fee will increase each year at the same percentage increase as the Consumer Price Index of 3.5%. Because of the recycling fee, the subsequent revenue increases from $0 at the W2E plant inception to over $6 million in the year 2036. We assumed that the fee increase will be set to automatically increase every year provided the increase does not exceed actual cost of the programs. Automatic increases can reduce uncertainty for fee-payers, because they will know about scheduled increases in advance. Also, small annual increases can reduce the need for periodic larger increases ("spikes") in fee amounts.

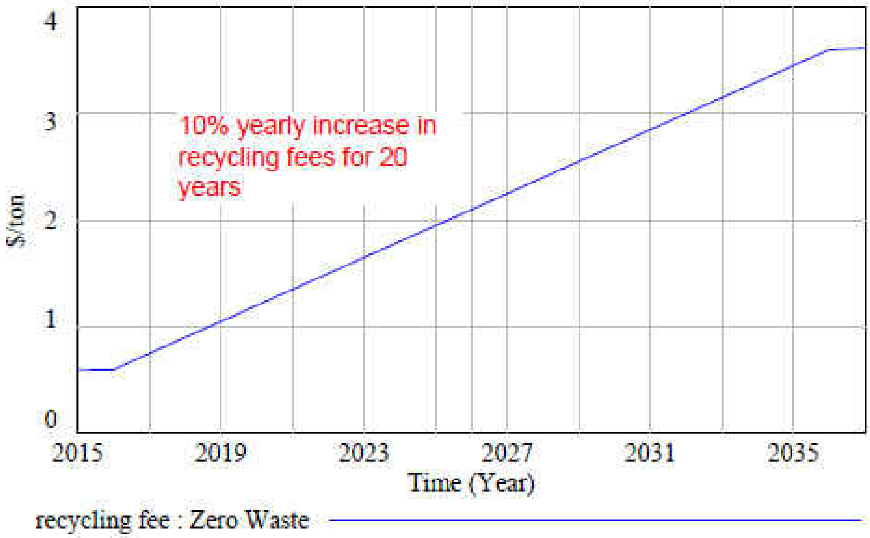


Figure 8-17. Model results – Zero Waste – recycling fee

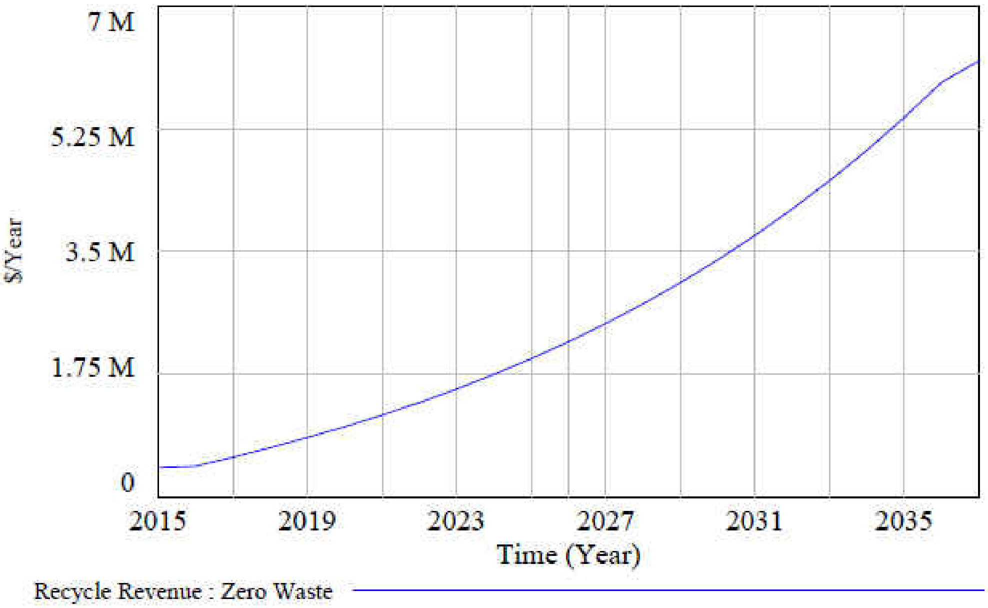


Figure 8-18. Model results – Zero Waste –recycle revenue

As for the construction and demolition (C&D) materials, we suggest that cost recovery fee is collected when a building permit or demolition permit is issued, no fees will be collected at the MUC for this service. One disadvantage of assessing a fee on C&D material as a condition of receiving a building permit is that it increases the total cost burden of receiving a building permit. Another suggestion would be to assess franchise fees or business license taxes on the C&D facilities themselves, again no fees will be collected at the MUC for this service. Another disadvantage of this approach is that the fee would apply to facilities that are located in the County, as the County would have no authority to assess franchise fees on facilities that are located in another jurisdiction.

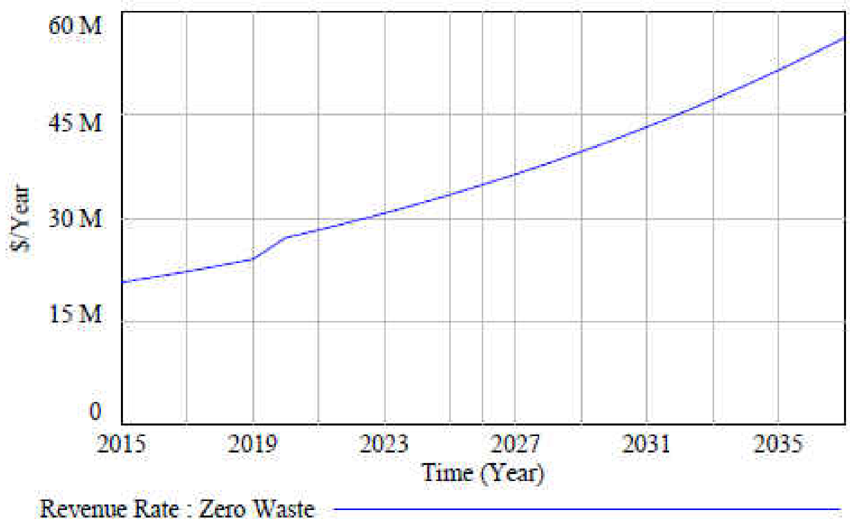


Figure 8-19. Model results – Zero Waste – revenue rate

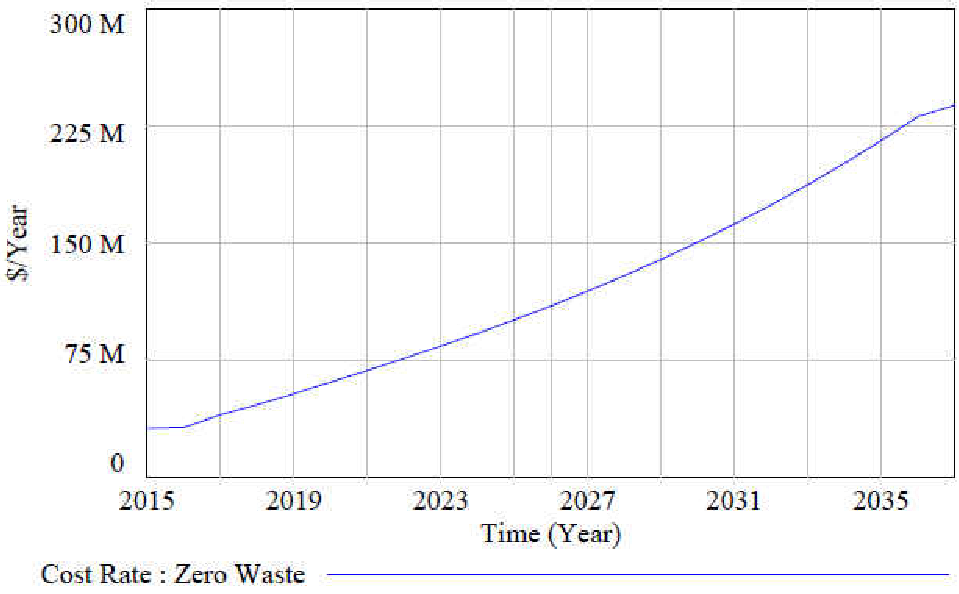


Figure 8-20. Model results – Zero Waste – cost rate

From a revenue-cost comparison, using the 10% gradual increase and recycling fees over 20 years will not provide a break-even point at any stage during this period. The cost of upgrading/upsizing the W2E plant to accommodate the incinerated waste increase, along with additional incidental cost for O&M will require more than double the projected revenue as indicated on Figure 8-19 and Figure 8-20. Revenue and cost seem to be proportional increase during the study period, further analysis for any revenue mechanism should include a thorough legal review and a cost study to confirm that costs attributed to a fee are appropriate, not recovered by another fee, and fee revenue does not exceed cost recovery. Again, the model does not take into account any financial impacts (whether revenue or cost) outside the physical perimeters of the municipal complex for implementing the zero waste policy. This is beyond the intent and the scope of this analysis, but it does include the cost within the plant to support this policy.

For the sake of future research, other possible financial impacts as a result of the zero waste policy may include:

1. Fees assessed on the hauler, which includes a group of various fees that are assessed on haulers, including franchise fees, public education fees, billing fees, administrative fees, etc.
2. Solid waste development Impact Fees, which includes fees designed to help a municipality recover the initial capital costs associated with expanding its solid waste operations to accommodate and serve new developments.
3. Vehicle impact fees, which includes fees that are charged to collection service providers to recover street maintenance costs associated with the collection of solid waste, recycling, and yard waste.
4. Street sweeping fees. These are designed to recover costs of street sweeping by applying a portion of the street sweeping cost to each user, either on a per-account basis, or on a percentage basis.
5. Host fees assessed on solid waste facilities. Host fees are fees charged to solid waste facility operators. Such facilities include landfills, transfer stations, or material recovery facilities ("MRFs"). Host fees are designed to recover street maintenance, litter abatement, code enforcement or other costs resulting from the impacts of the facility.
6. Extended producer responsibility fees and advanced disposal or advanced recycling fees, this is a policy approach that extends the responsibility of producers for their

products throughout the products' lifecycles. There are generally no governmental fees associated with these fees. Governmental fees are more likely to take the form of an advanced recycling fee, where the government collects a fee at the point of sale for a particular product, and uses the fee revenue to fund recycling programs for that type of product.

7. Revenues from the sale of carbon credits. Carbon credits may be available for sale if they are allowed for recycling programs through a future "cap-and-trade" system for greenhouse gas emissions, which may be established in California or the entire United States in the next few years.

8.5 Policy analysis – 3rd scenario “Build-Operate-Transfer” Policy

Pasco County is contemplating a build-operate-transfer policy for a new W2E plant in the year 2016 with a design capacity of 1,050 ton/day. The county is implementing a public–private partnership (PPP) initiative whereas a private entity contracts with the county to finance, design, construct, and operate the facility for a certain duration, usually 20 to 30 years. During this period the private entity has the responsibility to raise the finance for the project and is entitled to retain all revenues generated by the project and is the owner of the facility. One source of revenue specific to W2E plant is the county’s subsidy for per ton of waste received by the facility, which is the tipping fee in the model. After the agreed upon period is reached the facility will be then transferred to the county at the end of the period without any compensation to the private entity involved.

In this scenario, the county will provide the land, a stable supply of municipal solid waste, and an adequate amount of tipping fee to guarantee the profitability of the project. The county will also give a higher electricity generation purchasing price to the private partner.

This scenario allows the county to deal with the emerging waste management increase without raising huge amount of fund itself, therefore solves the problem of heavy financial burden of W2E on the local economy. It also acts as an incentive for private business development, and serves as a mechanism to help the private entity get easy bank loan of huge amount.

We will model this scenario starting from year 2016 for a period of 20 years, with the county incurring an approximate incidental expenses at the beginning of the period in the amount of \$2 million relative to initiating this policy. At the end of the contractual period, namely the year 2036, the county the W2E will assume full responsibility of the plant including its operation and maintenance costs.

8.6 Results and Discussion – 3rd scenario

This scenario alleviates the economic burden of high capital cost on the county, which in return, ensures the profitability of the plant owner through the PPP contract. There are several indicators that we tracked in this scenario, the cost rate, revenue rate, tipping fees, and electricity sales.

Cost rate - For this scenario, the model excludes the operation and maintenance cost of the W2E plant for the first 20 years, however all other costs remain in effect. The County will continue to provide basic municipal solid waste management regardless of the policy, and cost will increase due to continued population growth and the resulted generated waste. At year 2036, the county will take possession of the W2E plant and will assume all costs, this is depicted as a spike on the graph, where the cost will jump from about \$20 million per year to about \$27 million per year.

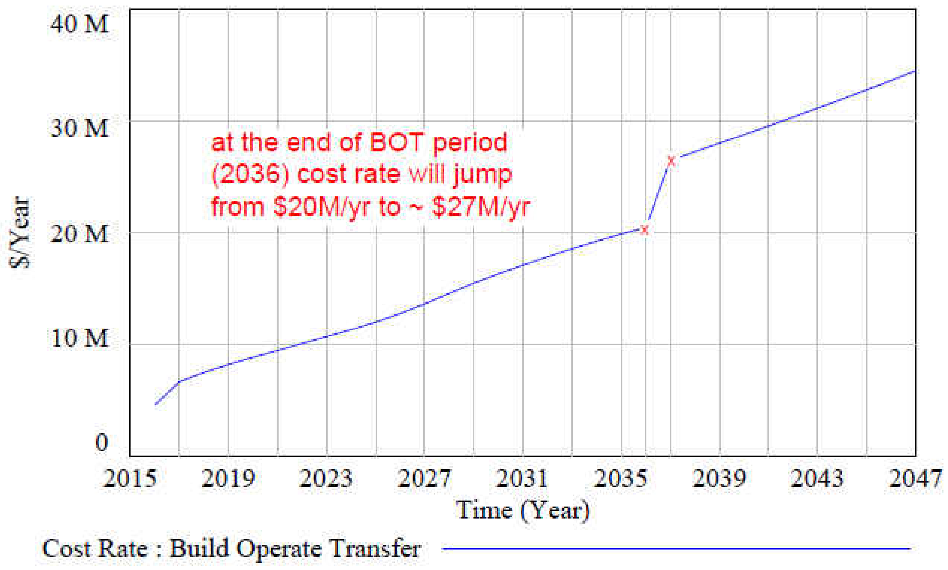


Figure 8-21. Model results – Build-Operate-Transfer cost rate

Revenue rate – the model also excludes any revenue from electricity generation during the build-operate-transfer period of 20 years, and the county will continue to generate revenue tied to the complex from other sources such as the garbage fees. After the transfer of the W2E plant to the county, year 2036, additional revenue is observed as a spike on the graph due to electricity sales.

It is worth noting that the model is built on a balanced budget between cost and revenue. The assumption is valid because the county is a non-profit entity that at minimum has to generate enough revenue to cover its costs or balance its budget through taxation and other applicable fees.

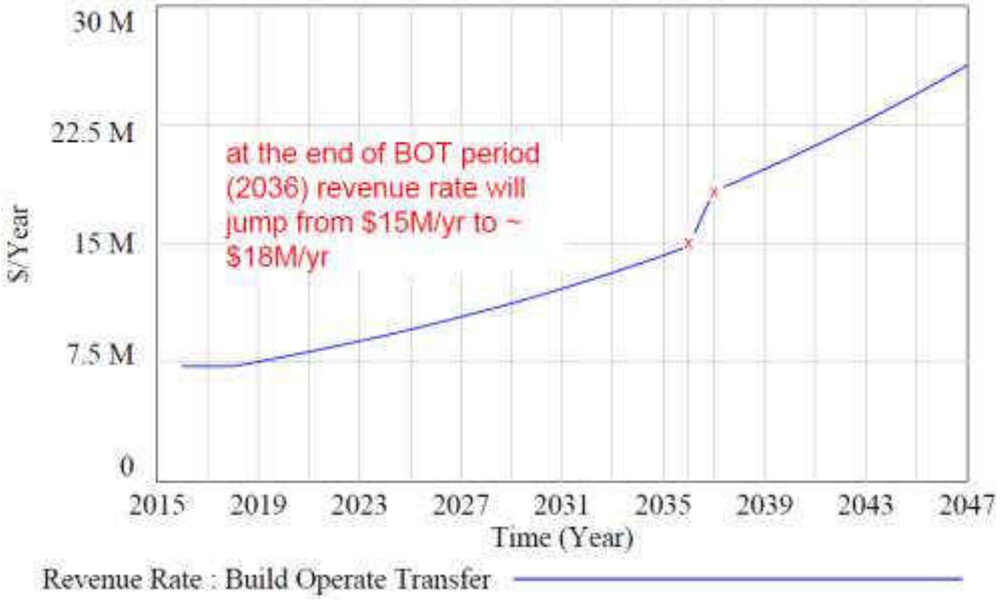


Figure 8-22. Model results – Build-Operate-Transfer revenue rate

The tipping fee has a significant impact on the balance sheet of this policy. Part of this policy is to allow the private entity to profit from this project through the tipping fee mechanism.

As shown on Figure 8-23, the tipping fee should not be less than $15/ton at least during the first five years. Through the life cycle of this policy, population growth will yield increase in waste generation which will either be collected individually as garbage or hauled off to the municipal utility complex by private haulers. If it is collected, then each address is charged a garbage collection fee, and if it is hauled then the hauler will be charged a tipping fee. Since the model is attempting to balance cost and revenue, it adjusts the fee downwards as the number of customer increases. Several tipping fees have been tested in the model to see its profitability. The study shows that the build-operate-transfer policy reduces the budget burden on local government and the economic risk on the investors, especially local economy is not developed enough to support a high tipping fee.

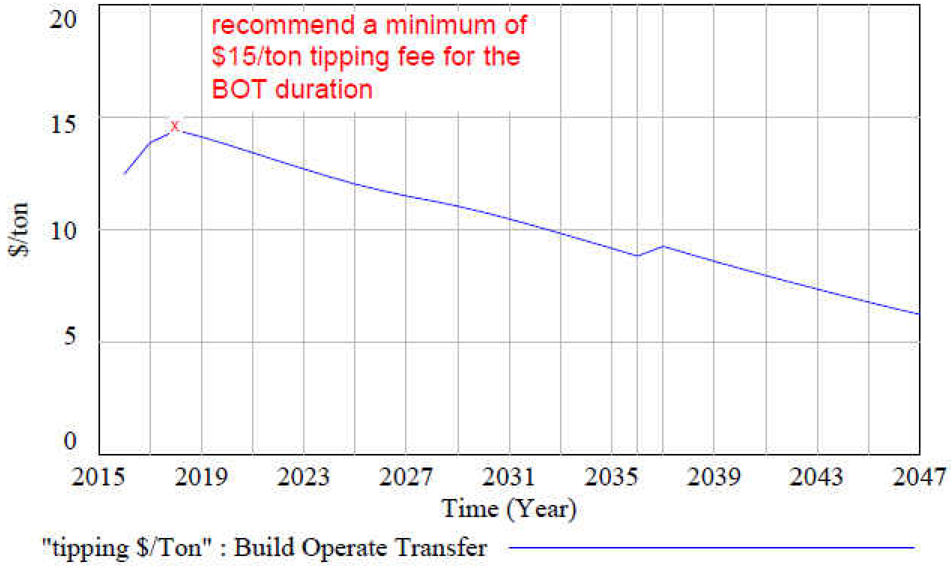


Figure 8-23. Model results – Build-Operate-Transfer tipping fees $/ton

The electricity sales is based on a higher electricity generation purchasing price of $100/MWh and is reflected in Figure 8-24. The support of the county to building a W2E plant stimulates the rapid development of the industry and guarantees the profitability of the build-operate-transfer scenario. The most important policy supporting W2E is the “grid electricity pricing”, applying specifically to W2E power by the county.

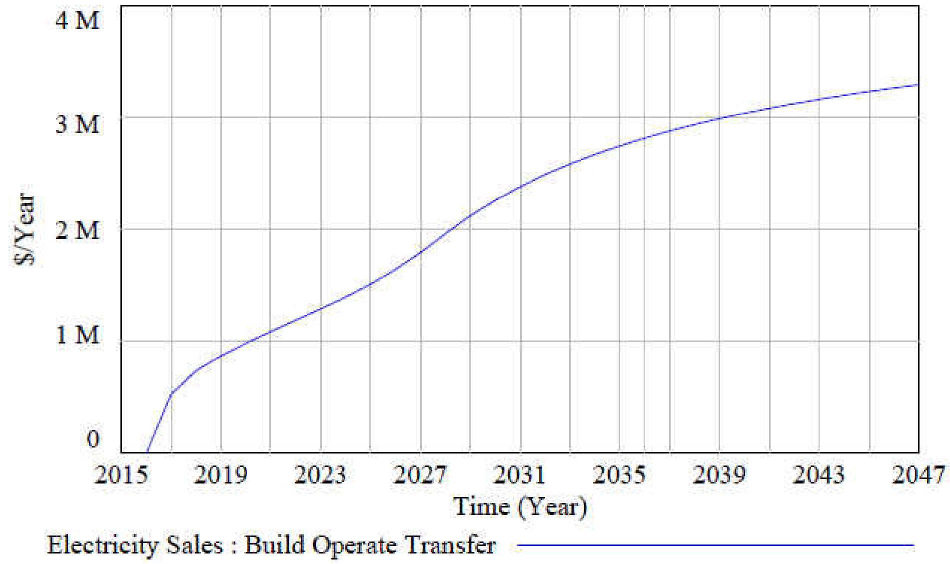


Figure 8-24. Model results – Build-Operate-Transfer electricity sales

CHAPTER 9
CONCLUSION

Taking advantages of the feedback processes that arise in an eco-industrial park due to the different decisions made by their makers, this paper constructed a dynamic model capable of generating different simulation paths. The differences in these paths are justified by the influence of physical, environmental, socio-economic factors as well as by the diversity of governmental strategies that are used, such as adoption of different GHG emission rules, or an increase in budget to build more schools. The results suggest that the municipal utility complex will contribute to the GDP and to increasing the budget for education to fund new schools, which will lead to boost in the level of skilled labor. The population does show a perceptible improvement as a result of building the utility complex. Finally, it seems important to stand out that without governmental policies such complexes will not be constructed. Also, the economic growth is influenced by different factors that are not studied in this paper, the model can be widened in different directions so as to analyze the modification of the economic growth when more, or new, factors influence the production as well as the implementation of policies that control its desirable degree of use.

One of the more difficult aspects of developing this strategic level aggregated model was parameter estimation. Very little data exists in aggregate form for such things as % of waste combusted or average decay rate for houses. Almost no data exists for cost of programs to implement changes in things like consumer behavior towards waste reduction or increasing recycling. What is the cost, for example, of a public education campaign that will result in an increase of 10% in consumer diversion? Or the cost to enforce a mandated reduction in packaging waste? How much social or political effort would it take to site enough alternative disposal facilities to increase capacity by 10,000 tons/per day relative to the amount it would take to convince people to reduce their consumption by 10%? The model simulation runs discussed above are only a few of the analyses possible with this model. As with other resource management models, the overall lesson is that there is no “silver bullet”, no magic solution that will achieve everybody’s goal with minimal cost, regardless of the specific parameters used.

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